(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 493 795 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **91122237.0**

(22) Date of filing: **27.12.91**

(51) Int. Cl.[5]: **G05G 9/04**, G05G 5/03, G06K 11/18, G06F 3/033, B25J 13/02

(30) Priority: **31.12.90 US 636318**

(43) Date of publication of application: **08.07.92 Bulletin 92/28**

(84) Designated Contracting States: **DE FR GB IT**

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(54) **Hand controller.**

(57) An active virtual pivot hand controller (10) using motors to control reflective forces and torques. Degree of freedom parameters, stops, and reflective force rates may be easily modified without altering hardware. The location of the virtual pivot of the hand controller may be likewise readily changed.

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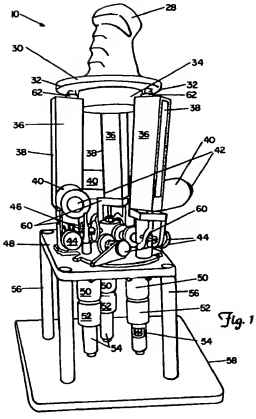
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Fig. 1

Field of the Invention

The present invention pertains to hand controllers according to the preamble of claim 1 and particularly to aircraft hand controllers. More particularly, the invention pertains to displacement aircraft or space vehicle hand controllers.

Related Art

The related art involves conventional hand controllers which rotate about a fixed axis in the base, require movement of both the arm and the wrist, have a high force displacement gradient, and have either no or complex proprioceptive feedback.

In recent years, space and weight constraints in modern aircraft have resulted in compact fly-by-wire or fly-by-light control systems. Such systems reduce the size and weight of flight control hardware in the cockpit. In addition, these systems permit a side-arm controller configuration that reduces obstruction of the instrument panel area directly in front of the pilot. Two general configurations of those compact controllers have been developed--rigid and movable displacement. Rigid controllers measure the force of the control input and have no movement associated with input magnitude. Moveable controllers have a range of motion of about ± 5 cm (± 2 inches) to ± 10 cm (± 4 inches) associated with the magnitude of the control input. The force required to fully displace a moveable controller may be quite small, although the inclusion of a force-displacement gradient has been found to improve control performance.

Difficulties are associated with both types of hand controllers. Rigid controllers may produce severe operator fatigue due to a lack of proprioceptive feedback to tell the pilot how much force he is exerting. That difficulty can be reduced by allowing for a small (i.e., ± 6 mm or ± 1/4 inch) amount of displacement or wobble unrelated to the force-output function. Further, rigid controllers provide fairly imprecise control and suffer from input axis cross-coupling, again due to the poor proprioceptive feedback provided to the operator.

Moveable controllers can provide reasonable control when a fairly heavy-force output gradient (i.e., ≥ 6,8 kg or > ± 15 pounds at full displacement) is used; however, these force requirements result in operator fatigue. At lower force requirements, control imprecision and axis cross-coupling are resulting problems.

Some of these problems were solved upon the conception and development of a moveable hand controller configuration that permits accurate control while requiring a relatively low force-displacement gradient. Also, such hand controller is useful in a side-arm configuration in that it allows the operator's arm to remain essentially motionless in an arm rest while control inputs are made about the fulcrum of the wrist. When the operator provides an input, such hand controller assembly is rotated in an arc having its center at the operator's wrist and/or center is translational. The hand controller also has the advantage of rotation about the operator's wrist joint, thus requiring movement of the wrist only. In other words, that hand controller has a "virtual pivot" that permits inputs to be made about any point in space and the controller translates movement of the controller grip about a point in space (such as the operator's wrist joint) into movements of a sensor about an internal reference point thereby permitting one hand controller to optimally function for all hand sizes. However, that controller has a grip and a sensor platform with a small-displacement and a motion base with spring-loaded legs for flexibility. Such hand controller is disclosed in EP-A1-0 363 739.

Departing from this known hand controller, it is the object of the present invention to further improve it so that it can be matched to different applications. This object is achieved according to the characterizing features of claim 1. Further advantageous embodiments of the improved hand controller may be taken from the dependent claims.

Summary of the Invention

The present invention is still yet a further improvement on the related art. Not only does the present invention have a virtual pivot which accommodates variations in operator action, have six degrees of freedom, and variable pivot point locations; the invention is adaptable for providing various forces and torques and displacements and rotations and provides force feedback which simulates spring-type feedback but having different rates, various stop positions, variable damping, and a variety of reflective conditions to the controller environment including impact, proximity, limits, etc. The system of the invention has a hand controller incorporating system actuators, system sensors and feedback actuators which are connected to system control and force feedback control mechanisms which implement a variable control algorithm. The controller has a hand grip platform which is supported by telescoping legs. Linear actuators drive the

telescoping motion in the legs. Motors drive radial angular motion at the universal joints which attach the legs to the base plate. A force/torque sensor is attached to the hand grip platform and monitors control inputs from an operator of the hand controller. There are angular potentiometers, linear potentiometers, and motor tachometers associated with the telescoping legs. The potentiometers provide a measurement of the position and attitude of the platform with respect to the base. Signals from the force/torque sensor, angular potentiometers, linear potentiometers and motor tachometers are input into the control system. The control system sends signals to the motors to drive the hand controller to the commanded configuration with the appropriate force and feel characteristics at the hand grip.

The virtual pivot of the hand controller system accommodates a wide variety of operator sizes with a "floating" pivot point. Motors and controllers replace springs of the related art hand controller and yet provides force feedback or "feel". Spring rates, spring tension, damping rates, stop positions, the number of control axes, the dimensions and range of control axes, and force reflection characteristics may be programmed with various values based on specific requirements into the control system. The programmability and flexibility of the hand controller system permits the controlling of a large and varied range of devices with a single hand controller. The hand controller system may be programmed to compensate for various gravities, various gravity and inertial effects, or for gravity-free environments. Applications of the hand controller system include use in space stations, space vehicles, helicopters, fixed-wing aircraft, underwater vehicles, robotic vehicles, robotic arm controls, and other applications.

Brief Description of the Drawings

Figure 1 is a drawing of hand controller.

Figure 2 is an overview diagram of the hand controller, control system, and the controlled system.

Figure 3 is a graph showing the relationship of hand grip-applied force/torque versus hand controller movement displacement profiles.

Figure 4 illustrates the vector relationships between base and platform coordinate frames of the virtual pivot hand controller.

Figure 5a and 5b constitute a signal flow diagram of the control system and motor channels.

Description of the Preferred Embodiment

Figure 1 reveals an adaptable six degree of freedom virtual pivot hand controller 10. Virtual pivot hand controller 10 has a hand grip 28 for the operator's input. Hand grip 28 is connected through grip platform 30 to six degree of freedom force and torque sensor 34. Force and torque sensor 34 is an F/T series, model 75/250 sensor from Assurance Technologies, Inc., of Garner, NC 27529. Grip platform 30 is connected to shafts 62 via ball joints 32. Three shafts 62 extend into three linear actuators 36, respectively. Linear actuators 36 cause shafts 62 to extend out of actuators 36 or to withdraw into actuators 36. The amount of shaft 62 extending out of linear actuator 36 is measured by linear potentiometer 38. Linear actuators 36 are driven by motors 40 thereby causing the extension or withdrawal of shafts 62. The withdrawal or extension of shafts 62 via ball joints 32 raise, lower, tilt, rotate and/or laterally move grip platform 30 and hand grip 28. The activity of motors 40 driving linear actuators 36 is monitored by tachometers 42. Linear actuators 36 are attached to universal joints 60, respectively. The other ends of the universal joints 60 opposite of linear actuators 36, are effectively attached to base plate 48. Six potentiometers 44 are, respectively, attached to universal joints 60 for measuring the angles of linear actuators 36 relative to base plate 48. The angle of linear actuator is 36, relative to base plate 48, is driven and set by motors 52 via gear heads 50 and worm and worm wheel assemblies 46. Gear heads 50 are attached to motors 52 through base plate 48 to worms 46. Worms 46 drive worm wheels 46 which are attached to the portions of universal joints 60 that are rigidly attached to linear actuators 36, respectively. Worms 46 driving worm wheels 46 set linear actuators 36 and shafts 62 to particular angles of inclination. Motors 52 are monitored by tachometers 54. Base plate 48 is supported by a surface 58 with structural supports 56. Surface 58 represents the place or area upon which hand controller 10 is situated and mounted.

Figure 2 reveals an overall diagram of the adaptable six degree of freedom virtual pivot hand controller 10 system. Hand controller 10 outputs sensor signals 20 from six degree of freedom force and torque sensor 34, linear potentiometers 38, angular potentiometers 44, motor tachometers 42 and motor tachometers 54. Sensor signals 20 are input to control system 12 which is a processor and specifically a Motorola VMEbus 68020 single board microcomputer, having system control 14 and force feedback control 16. Force and torque sensor 34 which is attached to hand grip platform and hand grip monitors the control inputs from the operator. Control system 12, in response to sensor signals 20, sends feedback signals to

motors 40 and 52 to drive hand controller 10 in accordance with the commanded configuration, having appropriate force and feel characteristics. The force and feel characteristics are determined by force feedback control 16 and response to sensor signals 20 revealing force, torque, position and rate, and signals from controlled system 18 sensors indicating proximity, force, field dynamics, etc., in response to driving signals 22 to system actuators such as motors, propulsion, etc. Hand controller 10 uses motor biasing to generate the force and feel of springs, damping and mechanical deadbands as illustrated in Figure 3. Figure 3 is a graph of hand grip applied force and torque versus displacement profiles of hand grip 10.

Control interface 22 required to determine hand control 10 orientation and translation in six degrees of freedom contains nine potentiometer measurements (three per leg) that define three position vectors of grip platform 10, corresponding to three fixed ball joints 32, with respect to the three base leg pivot points at the ends of shafts 62. During system calibration, a fixed displacement vector (from the origin of platform 30 coordinate frame) of the operator's wrist joint is estimated. Figure 4 shows the vector relationships between base 48 and platform 30 coordinate frames. Processor or control system 12, through force feedback control 16, returns three Euler angles and three linear translations from nominal platform 30 origin. Additionally, force and torque sensor 34 inputs are used in either position or rate mode to command a six degree of freedom velocity that motorized legs 36 and shaft drives 46 are to deliver. Thus, processor or control system 12 must first solve the geometric task of computing orientation and translation, and then compute the requisite leg or shaft rotational and linear velocities that result in the commanded and controller state.

Kinematic solutions to the hand grip platform Euler angles (defining attitude angles) and linear displacements from the center of the coordinate frame are obtained by use of nine potentiometers, 38 and 44. Fewer potentiometers can accomplish the same task of monitoring as the nine potentiometers. Telescoping legs or shafts 62 (whose links are actuator 36 driven) are attached to platform 30 by ball joints 32 and to base 48 by double-gimbaled motorized joints 60. Outer gimbals 60 are rigidly attached to base 48, are motor 52 driven, and cause a roll motion about the leg or shaft 62 motor axis of rotation. Outer gimbal 62 axis defines the leg or shaft 62 coordinate frame X-axis for each of the three legs or shafts 62. These three axes are each oriented along the radial directions with respect to the center of base 48. This results in the forward base 48 point having its motor axes along the X-axis of the base 48 coordinate frame. Azimuth angles ϕ_i to the other two base 48 points have constant values of 120 and 240 degrees, respectively. Inner gimbals 60 allow rotation about the respective leg or shaft 62 pitch axes. Designating the length of the three legs 62 d_i, where i equals 1, 2, 3, and is defined $0 < d_{imin} < d_i < d_{imax}$. Then the position vectors of platform 30 ball joints 32 with respect to base 48 frame S_B:

$$\vec{P}_i = E_i(\Psi_O)\,E(\theta_i, \phi_i) \begin{bmatrix} 0 \\ 0 \\ d_i \end{bmatrix} + \vec{P}_{Bi};\ i = 1, 2, 3 \qquad (1)$$

where

$$E(\theta_i, \phi_i) = \begin{bmatrix} \cos\theta_i & 0 & \sin\theta_i \\ \sin\theta_i \sin\phi_i & \cos\phi_i & -\cos\theta_i \sin\phi_i \\ -\sin\theta_i \sin\phi_i & \sin\phi_i & \cos\theta_i \cos\phi_i \end{bmatrix} \qquad (2)$$

and

$$E_i(\Psi_0)=\begin{bmatrix} \cos\Psi_0 & -\sin\Psi_0 & 0 \\ \sin\Psi_0 & \cos\Psi_0 & 0 \\ 0 & 0 & 1 \end{bmatrix}; \Psi_0 = 0, 120, 240 \text{ deg} \quad \text{for } i = 1, 2, 3 \tag{3}$$

Processor of control system 12 is a Motorola VMEbus 68020-board microcomputer housed in a standard Motorola chassis having several analog-to-digital interface cards. Six tachometers 42 and 54 on three legs 62 measure motor speeds of leg-extending or retracting motors 40 and leg-angular rotating motors 52. There are two motors, 40 and 52, per leg 62. Linear potentiometers 38 measure leg 62 extension and two angular potentiometers 44 per leg 62 measure angles of each leg 62 relative to base 48. There is a total of nine potentiometers 38 and 44.

Rate and position control modes of hand controller 10 differ. In the position mode, removal of grip, force and torque commands from the operator causes hand controller 10 to remain at its latest attained attitude and linear displacement. Removal of input in the rate mode will cause a return of hand controller 10 to the initial displacement origin. Any of the six degrees of freedom of hand controller 10 may be locked out as desired. Software stops are provided to prevent hand controller 10 from running into hard stops which might cause damage.

Figures 5a and 5b constitute an overview signal flow diagram of hand controller 10 input and motor control channels. This diagram has correlation with the program listing at the end of this description. Force/torque sensor 34 is a strain gauge type of sensor for detecting applied force and torque to hand grip 28 of controller 10. Interface 13 provides for keyboard or other type of input to the processor which includes input command processing 68 and motor command 70. Interface 13 is a RS-232 terminal interface for operator inputs of the controller 10 processor. Control system 66 provides for needed interaction among force and torque sensor 34, input command processing 68 and interface 13. Control system 66 includes sensor 34 electronics and control and may incorporate a Lord preprocessor and a Lord controller for sensor 34, from Assurance Technologies, Inc., of Garner, NC 27529. Controller function 72 incorporates software to perform the calculations of required motor rates to equal commanded input velocities of translation and rotation by incorporation kinematic system equations. Orientation function 74 incorporates software to perform the calculations of the platform and/or virtual pivot translation and rotation with respect to the base coordinate system. Inputs represent shaft or leg lengths, elevations and azimuth angles obtained from the nine potentiometers 38 and 44 (three per shaft or leg). Function 74 incorporates reverse kinematic system equations in its calculations. External object or device 18 receives input for external control and outputs signals for providing reflected force or torque (i.e., "feel" dynamics), or alarms.

The following describes the geometric relationships. Position vectors of the pivots are defined by R_{Bi} and R_{Pi}, where i = 1, 2, 3, in the two separate frames S_B (the base 48 frame) and S_P (the platform 30 frame), results in

$$\bar{R}_{B1} = \begin{bmatrix} r_B \\ 0 \\ 0 \end{bmatrix}; \bar{R}_{B2} = \begin{bmatrix} -r_B/2 \\ (\sqrt{3}/2)r_B \\ 0 \end{bmatrix}; \bar{R}_{B3} = \begin{bmatrix} -r_B/2 \\ -(\sqrt{3}/2)r_B \\ 0 \end{bmatrix}$$

$$\bar{R}_{P1} = \begin{bmatrix} r_P \\ 0 \\ 0 \end{bmatrix}; \quad \bar{R}_{P2} = \begin{bmatrix} -r_P/2 \\ (\sqrt{3}/2) r_P \\ 0 \end{bmatrix}; \quad \bar{R}_{P3} = \begin{bmatrix} -r_P/2 \\ -(\sqrt{3}/2) r_P \\ 0 \end{bmatrix}$$

$$\bar{R}_C = \frac{1}{3} \sum_{i=1}^{3} \left[\bar{R}_i + \bar{R}_{Bi} \right] = \frac{1}{3} \sum_{i=1}^{3} \bar{R}_i$$

since the sum $\Sigma \bar{R}_{Bi} = 0$.
or

$$\bar{R}_C = \frac{1}{3} \sum_{i=1}^{3} E_i (\Psi_0) \cdot \begin{bmatrix} -d_i \sin \theta_i \\ d_i \cos \theta_i \sin \phi_i \\ -d_i \cos \theta_i \cos \phi_i \end{bmatrix}$$

The above dot represents a matrix dot product. Referring to Figure 4, the platform 30 $\hat{X}_P$ unit vector is directed from the center toward P_1. The $\hat{Y}_P$ unit vector is parallel to the line from P_3 to P_2. Then,

$$\hat{X}_P = \left[\frac{1}{r_P} \right] \left[\bar{R}_1 - \bar{R}_C \right] = \left[\frac{2}{3} \bar{R}_1 - \frac{1}{3} (\bar{R}_2 + \bar{R}_3) \right]$$

$$\hat{Y}_P = \left[\frac{1}{\sqrt{3}\, r_P} \right] \left[\bar{R}_2 - \bar{R}_3 \right]$$

$$\hat{Z}_P = \hat{X}_P \times \hat{Y}_P = \left[\frac{2\sqrt{3}}{9 r_P^2} \right] \left[\bar{R}_1 \times \bar{R}_2 + \bar{R}_2 \times \bar{R}_3 + \bar{R}_3 \times \bar{R}_1 \right]$$

The direction cosines of the $\hat{X}_P$, $\hat{Y}_P$, and $\hat{Z}_P$ unit vectors are the components of the preceding vector equations. The Euler rotation matrix from S_B to S_P is then

$$E_{P/B} = \begin{bmatrix} \hat{X}_P \cdot \hat{X}_B & \hat{Y}_P \cdot \hat{X}_B & \hat{Z}_P \cdot \hat{X}_B \\ \hat{X}_P \cdot \hat{Y}_P & \hat{Y}_P \cdot \hat{Y}_B & \hat{Z}_P \cdot \hat{Y}_B \\ \hat{X}_P \cdot \hat{Z}_B & \hat{Y}_P \cdot \hat{Z}_B & \hat{Z}_P \cdot \hat{Z}_B \end{bmatrix} = \left\{ e_{ij} \right\}.$$

The above dots represent vector dot products.

All information concerning the relative attitude orientation between the base 48 and platform 30 frames is contained in the Euler matrix $E_{P/B}$. Euler angles can be defined in 24 different ways depending on the sequence of rotations (in a positive sense about each of three axes). There are 12 permutations starting with either frame S_P or S_B, or 24 total. Each set of three angles is not interchangeable (except for very small rotations). Each set does, however, result in the same rotation of one frame to another when applied in its specific sequence.

The following set arises from a yaw rotation about the S_B z axis followed by a pitch rotation bout the y axis and a final roll about the x axis:

$\psi_P = \tan^{-1}(e12/e11)$ = Yaw
$\theta_P = \sin^{-1}(e13)$ = Pitch
$\phi_P = \tan^{-1}(e23/e33)$ = Roll

Each rotation assumes the right-hand rule for positive sense. The inverse transformation performs a roll-pitch-yaw transformation (in that order) which is not uncommon in the aircraft industry.

The following describes the platform velocity equations. Tachometers 42 and 54 mounted on the handcontroller 10 legs and roll axis shafts are used in a velocity feedback controller 16 that drives each motorized leg 62 to null a separate commanded velocity. These six velocities are in turn computed according to the six signals from force/torque sensor 34 (after biasing to provide reflected force or torque dynamics for the operator).

At present, handgrip 28 force signals are interpreted as referenced to the base 48 coordinate frame as a linear velocity command. The coordinate system used is arbitrary and can be easily redefined in processor code and provided as an optional handcontroller 10 operating mode at a later time if desired.

The inertial velocity $\vec{V}_i$ of each leg 62 is composed of the linear velocity of the platform 30 center summed with the rotational velocity about the center, that is

$$\vec{V}_i = \frac{d}{dt}\vec{R}_i = E_i(\Psi_0) \left\{ \frac{d}{dt} \left[E_i(r_i, d_i) \cdot \begin{bmatrix} 0 \\ 0 \\ -d_i \end{bmatrix} \right] \right\}$$

$$= \vec{V}_C + \vec{\omega}_P (\vec{R}_i - \vec{R}_C); \quad i = 1, 2, 3$$

or

$$\vec{V}_i = \Omega_i (\Psi_0, \theta_i, \phi_i, d_i) \cdot \begin{bmatrix} \dot{\theta}_i \\ \dot{\phi}_i \\ \dot{d}_i \end{bmatrix} = \vec{V}_C + \vec{\omega}_P (\vec{R}_i - \vec{R}_C);$$

$$i = 1, 2, 3$$

where θ_i, ϕ_i, and d_i are the time rate of change of angles θ_i ϕ_i, and leg length d_i for each leg. Then,

$$\begin{bmatrix} \dot{\theta}_i \\ \dot{\phi}_i \\ \dot{d}_i \end{bmatrix} = \Omega_i^{-1} \left[\vec{V_C} + \vec{\omega_P} \left(\vec{R_i} - \vec{R_C} \right) \right]; \quad i = 1, 2, 3$$

In the above equation, only the expressions for leg roll and length rates are of interest as the handcontroller 10 leg 62 pitching rates are automatically driven by mechanical constraints. This solution requires inversion of a 3 by 3 matrix, where

$$\Omega_i \left(\Psi_0, \theta_i, \phi_i, d_i \right) =$$

$$E_i(\Psi_0) \cdot \begin{bmatrix} 0 & -d_i \cos\theta_i & -\sin\theta_i \\ d_i \cos\theta_i \cos\phi_i & -d_i \sin\theta_i \sin\phi_i & \cos\theta_i \sin\phi_i \\ d_i \cos\theta_i \sin\phi_i & d_i \sin\theta_i \cos\phi_i & -\cos\theta_i \cos\phi_i \end{bmatrix};$$

$$i = 1, 2, 3$$

The platform 30 angular velocity vector input commands, ω_P, above are referenced to S_B; if they are instead referenced to S_P, they are simply converted by the inverse Euler transformation as follows:

$$\omega_P = \begin{bmatrix} \omega_X \\ \omega_Y \\ \omega_Z \end{bmatrix}_B = E^{-1}{}_{P/B} \begin{bmatrix} \omega_{Xc} \\ \omega_{Yc} \\ \omega_{Zc} \end{bmatrix}_P$$

The inverse Euler matrix is the transpose of the matrix since the coordinate frame is orthogonal and Cartesian.

In summary, one feature of hand controller 10 is that the sensed location of the pivot point can be set arbitrarily. It can be set through the center of grip 28, above or below it, or be centered inside the operator's wrist. For example, with a pivot point below grip 28, it would act like a conventional military aircraft hand controller having the pivot point where the control stick attaches to the floor or deck of the aircraft. However, with the pivot point above grip 28, the top of the grip would be seemingly attached to a point above it and the grip would swing freely below it. The programmability of the pivot point provides for maximum flexibility and adaptability of hand controller 10. These changes in location of pivot point can be made by entering the appropriate software commands in control system 12. An initial setting can be made by the operator through the movement of his or her wrist for setting the virtual pivot and control swing and rotation dimensions in accordance with and to match the wrist movement. Other operating characteristics can be changed simply by altering the software. Such things as break out forces, the degree of freedom available, damping rates, spring tensions and velocity rates can be modified without altering the hardware of control system 12 or hand controller 10. Based on information from the vehicle or object being controlled, the

operator is given feedback through grip 28. This capability is force reflection and usually involves providing tactile feedback through grip 20 when the control object 18 (e.g., a robot arm or vehicle) contacts the target or other object. The combination of a programmable virtual pivot point having an active hand controller 10 allows the operator or user to configure hand controller 10 to match or meet the demands or needs of a particular task and user.

Motor-driven force feedback (microprocessor 12 control) replaces spring centering. Gradients of forces or torques versus displacements (in each of six axes), as shown in Figure 2, are stored as parameters that can be modified by keyboard 13 input. Such modification provides adaptability or programmability of key hand controller 10 operating characteristics including sensed (virtual) pivot axes locations and range of motion in each axis, sensed spring force reflection or the feel of grip 28 (i.e., force/displacement gradients), the capability, as desired, to implement bilateral force feedback from system 18 being controlled (via motor control feedback) to the human operator and the capability of operator-mode control to introduce menu-driven commands (via the VMEbus single-board computer).

APPENDIX

Software Listings for the Virtual Pivot Hand Controller

Filename	Description
handcntrlbowl.c	Stand-alone test program for the "controller" function.
myfunc50hz.2.29.90	Main program (interrupt driven).
hc4.c	Merged "controller" and "orientation" functions.
hc4.h	Data structure definitions.
dtoa.h	Digital-to-analog conversions.
atod.h	Analog-to-digital conversions.
mymath.h	Sun Microsystems, Inc. utilities.
bowl.c	Bowl demonstration mode declarations.
cmd_declarations.h	Operator's terminal input commands.
cmd_definition.h	Data structure definitions.
makefile	Compiler macro command file.

Note: Additional file listings attached are minor utilities and data type definitions or declarations common to many simmilar implementations.

```
/* .....Velocity Control Subroutine and Main Driver ..... */
/*      Project: Virtual Pivot Hand Controler (IR&D F4925-3000-2822)          */
/*
                                                                              */

/*      Description:    Theory of the C-Language code of this subprogram is
                        documented in the technical memo "Adaptable 6-DOF
                        Virtual Pivot Handcontroller: System Equations",
                        by W.C. Marshall, Dec 1989. Units are currently
                        "inches', radians, and unit time. Data I/O is via a data
                        structure as noted in the declarations.

                        Function "orient()" solves the "reverse kinematics"
                        problem given as input the desired platform's attitude
                        and relative position vector. Mean HEIGHT of the platform
                        specifies a positive distance along the "-z" axis. The "z"
                        axis is positive "down" with the "z" axis away from the
                        operator and "y" axis towards the right.

                        Function "controller()" computes the linear and angular
                        velocities (inches & radians per second) of each leg and
                        shaft motor. Input are the relative linear and angular
                        velocity vectors of the platform center wrt the base.
                        Platform attitude and relative position vectors wrt the
                        platform origin (9.5" above base origin) are also output.

                        In the actual mechanization, function "orient()" is not
                        presently needed as "pots" measure the actual leg and
                        shaft displacements.  Note that "zero" for the leg is when
                        the overall leg is at 9.5 inches and "zero" for shaft
                        rotation is when the leg is "vertical".                */

/* ..................................... Start of Global Declarations ..... */

#include <math.h>
#include <stdio.h>
```

```
#define RPLAT 2.5                       /* Platform radius                  */
#define RBASE 2.5                       /* Base radius to leg               */
#define HEIGHT 10.0                     /* Mean height of leg               */
#define RADDEG 57.29577951      /* Degrees per radian */
#define DEGRAD 0.01745329       /* Radians per degree */
#define TINY 1.0e-20                    /* A "small" number  */
#define SR2 1.41421356          /* = sqrt(2)          */
#define SR3D3 .57735027         /* = sqrt(3)/3        */
#define RPD2 RPLAT*.5           /* = (1/2)*RPLAT      */
#define RBD2 RBASE*.5           /* = (1/2)*RBASE      */
#define HALF .5                 /* = (1/2)            */

typedef struct sensor                   /* Interface structure for "HandCtrl" I/O data */
        {
        float d1,the1,phi1;             /* Leg #1 length & two angles       (Input)  */
        float d2,the2,phi2;             /* Leg #2 length & two angles       (Input)  */
        float d3,the3,phi3;             /* Leg #3 length & two angles       (Input)  */

        float dels,dely,delz;           /* Current platform offset from zero position*/
        float phi,theta,psi;            /* Current platform roll,pitch,yaw (radians)*/

        float vels,vely,velz;           /* Desired translational rates              */
        float ws,wy,wz;                 /* Desired angular rates (rad./sec.)        */

        float ph1dot,d1dot;             /* Angle & leg rate commands (Output)       */
        float ph2dot,d2dot;             /* Angle & leg rate commands (Output)       */
        float ph3dot,d3dot;             /* Angle & leg rate commands (Output)       */
        };

                        /* List of functions used by "main" */

void bowl();
void controller();
void orient();
void quat();
void euler();
void matmpy();
void matran();
void matinv();
void tranpose();
void smult();

                                        /* MISCELANEOUS */

static float epb[3][3];         /* Euler transformation matrix (Base-To-Platform)   */
static float bbp[3][3];         /* Euler transformation matrix (Platform-To-Base)   */

static float aib[3][3];         /* Leg #1 Euler matrix Ib to Li                     */
```

```
static float e2b[3][3];          /* Leg #2 euler matrix 5b to L2                    */
static float e3b[3][3];          /* Leg #3 euler matrix 5b to L3                    */

static float e1[3][3];           /* Leg #1 angular rate transform matrix            */
static float e2[3][3];           /* Leg #2 angular rate transform matrix            */
static float e3[3][3];           /* Leg #3 angular rate transform matrix            */
static float e1in[3][3];         /* Inverse of e1 matrix                            */
static float e2in[3][3];         /* Inverse of e2 matrix                            */
static float e3in[3][3];         /* Inverse of e3 matrix                            */

                                 /* KEY PARAMETER LIST DECLARATIONS */

static float ANGLE[3];           /*  Euler angles phi,theta,psi wrt 5b              */
static float ABATE[3];           /*  Platform rates Wx,Wy,Wz in 5b                  */
static float RP[3];              /* Platform centerposition wrt 5b                  */
static float VBL[3];             /* Platform velocity wrt 5b                        */
static float R1[3];              /* Position of Leg #1 at top in 5b                 */
static float R2[3];              /* Position of Leg #2 at top in 5b                 */
static float R3[3];              /* Position of Leg #3 at top in 5b                 */
static float V1[3];              /* Velocity of Leg#1 at top in 5b                  */
static float V2[3];              /* Velocity of Leg#2 at top in 5b                  */
static float V3[3];              /* Velocity of Leg#3 at top in 5b                  */
static float RP1[3];             /* Rel. position of Leg #1 wrt RP[1]               */
static float RP2[3];             /* Rel. position of Leg #2 wrt RP[1]               */
static float RP3[3];             /* Rel. position of Leg #3 wrt RP[1]               */
static float XP[3];              /* Platform Xp unit vector coordinates             */
static float YP[3];              /* Platform Yp unit vector coordinates             */
static float ZP[3];              /* Platform Zp unit vector coordinates             */
static float OUP1[3];            /* Motor rates for Leg #1                          */
static float OUP2[3];            /* Motor rates for Leg #2                          */
static float OUP3[3];            /* Motor rates for Leg #3                          */

static float PHIC;               /* Commanded initial roll orientation              */
static float THEC;               /* Commanded initial pitch orientation             */
static float PSIC;               /* Commanded initial yaw orientation               */
static float DELR[3];            /* Commanded initial position vector               */
static float RPC[3];             /* Platform position vector wrt 5b                 */
static float R1b[3];             /*Computed Leg vectors in 5b                       */
static float R2b[3];             /*Computed Leg vectors in 5b                       */
static float R3b[3];             /*Computed Leg vectors in 5b                       */
static float D1b[3];             /*Computed Leg vectors in 5b at B1                 */
static float D2b[3];             /*Computed Leg vectors in 5b at B2                 */
static float D3b[3];             /*Computed Leg vectors in 5b at B3                 */
static float LD1[3],LD2[3],LD3[3];/*Computed Leg vectors in SIL at B1 */
static float e5bc[3][3];         /* Computed matrix 5b to SIL for D1[3]             */
                                 /* Constant matrix 5b to SIL for D1[3] */
static float ek2[3][3] = {{-HALF,  SR3D2,.0},{-SR3D2,-HALF,.0},{.0,.0,1.0}};
```

```
static float sk3[3][3] = {(-HALF,-SR3D2,.0),(  SR3D2,-HALF,.0),(.0,.0,1.0)};

static float prate[3];                  /* Buffer for grip angular rate input   */
static float pvel[3];                   /* Buffer for grip linear velocity input        */
static float griploc[3] = {.0,.0,-3.13};        /* Grip position offset vector  */
static float grip[3];                   /* Grip vector in base coordinates              */
static float TEMP[3];                   /* Temporary vector storage             */
static float deltax,deltay,deltaz;      /* Used in main program                 */

static float d1,d2,d3;
static float the1,the2,the3;
static float phi1,phi2,phi3;
static float sthe1,sthe2,sthe3;
static float cthe1,cthe2,cthe3;
static float sphi1,sphi2,sphi3;
static float cphi1,cphi2,cphi3;
static float ph1d,ph2d,ph3d;
static float the1d,the2d,the3d;
static float d1d,d2d,d3d;
static float determ,temp;
static float d1c,d2c,d3c,d1c2,d2c2,d3c2;
static float phi1o,phi2o,phi3c;
static float the1c,the2c,the3c;

/* ..........................................BOWL DEMO DECLARATIONS ..........................................
static float RADIUS = 3.0;              /* Radius of bowl shape centered above origin           */
static float ALP = .78539816;   /* 45 deg. from vertical  in radians                    */
static float PID2 = 1.57079633; /* = (1/2)*PI radians or 90 deg.                        */
/* ..........................................................................................................
...........*/

void bowl(PX,PY,xbowl,ybowl,zbowl,phibo,thebo,psibo)

float PX,PY;                            /* Bowl parameters      -1.<Pi<+1.              */
float *xbowl,*ybowl,*zbowl;     /* Bowl rel.ocoord. wrt platform coord. origin   */
float *phibo,*thebo,*psibo      ;       /* Bowl surface attitudes                               */
{
float phi,the;

phi = PID2 - ALP*PX;
the = PID2 - ALP*PY;
*xbowl = RADIUS*cos(the)*cos(phi);
*ybowl = RADIUS*cos(the)*sin(phi);
*zbowl = RADIUS*sin(the) - RADIUS;
*phibo = PID2 - phi;
*thebo = PID2 - the;
*psibo = .0;
```

```
return;
}

/* ..........DEBUGING DECLARATIONS.....................*/
static int BUG00 = 0; /* =1 means set I(-UNUSED-)          */
static int BUG01 = 0; /* =1 means print epb[i][j]          */
static int BUG02 = 0; /* =1 means print ebp[i][j]          */
static int BUG03 = 0; /* =1 means print R1,R2,R3 BP        */
static int BUG04 = 0; /* =1 means print phid & cbid outputs */
static int BUG05 = 0; /* =1 means print Vi vectors         */
static int BUG06 = 0; /* =1 means print euler angles       */
static int BUG07 = 0; /* =1 means print IC attitude commands*/
static int BUG08 = 0; /* =1 means print euler matrix result */
static int BUG09 = 0; /* =1 means print dio,thio, phio     */
static int BUG10 = 0; /* =1 means print di,thei, phii      */
static int BUG11 = 0; /* =1 means print RPC[j]             */
static int BUG12 = 0; /* =1means print bi[j]               */

/* ************************************************************ */

main()

{
int j;

float delta = .2;
float xb,yb,zb,thb,phb,psb;
float PX,PY;
struct sensor sdata;
j = 0;

DELA[0] = .0;                   /* Set rel. position & attitude of platform.  */
DELA[1] = .0;                   /* these variables are defined wrt Sb.        */
DELA[2] = .0;
PHIC = .1;
THEC = .2;
PSIC = .3;

orient(&sdata);                 /* Compute platform leg orientation           */

sdata.velx  = .0;                       /* Set linear & angular velocities of the */
sdata.vely  = .0;                       /* Platform.linear velocities are defined */
sdata.velz  = 1.0;              /* wrt Sb with "z" down, "x" forward and  */
sdata.wx    = .0;                       /* "y" axis towards the right. Angular    */
sdata.wy    = .0;
sdata.wz    = 1.0;
```

```
controller(&sdata);              /* Compute motor velocity control              */

daltax = sdata.delx;
daltay = sdata.dely;
daltaz = sdata.delz;

/*.....................................Bowl Demo Test ..................................*/
PX = -1.;
PY = -1.;
for(j=0;j<10;j++)
{
        PX = PX + delta;
        PY = PY + delta;
        bowl(PX,PY,&xb,&yb,&xb,&phb,&thb,&psb);

        printf("PX,PY = %2.3f %2.3f  \n", PX,PY);
        printf("xb,yb,zb = %2.3f %2.3f %2.3f  \n", xb,yb,zb);
        printf("phb,thb,psbb = %2.3f %2.3f %2.3f  \n", phb,thb,psb);
};


                                /* DEBUG LOGIC  CONTROL */
if(BUG01>0) printf(" 01:epb[0][j] = %2.3f %2.3f %2.3f \n",epb[0][0],epb[0][1],epb[0][2]);
if(BUG01>0) printf(" 01:epb[1][j] = %2.3f %2.3f %2.3f \n",epb[1][0],epb[1][1],epb[1][2]);
if(BUG01>0) printf(" 01:epb[2][j] = %2.3f %2.3f %2.3f \n",epb[2][0],epb[2][1],epb[2][2]);
if(BUG02>0) printf(" 02:ebp[0][j] = %2.3f %2.3f %2.3f \n",ebp[0][0],ebp[0][1],ebp[0][2]);
if(BUG02>0) printf(" 02:ebp[1][j] = %2.3f %2.3f %2.3f \n",ebp[1][0],ebp[1][1],ebp[1][2]);
if(BUG02>0) printf(" 02:ebp[2][j] = %2.3f %2.3f %2.3f \n",ebp[2][0],ebp[2][1],ebp[2][2]);
if(BUG03>0) printf(" 03:R1,R2,R3,RP=%2.3f %2.3f %2.3f %2.3f \n",R1[0],R2[0],R3[0],RP[0]);
if(BUG03>0) printf(" 03:R1,R2,R3,RP=%2.3f %2.3f %2.3f %2.3f \n",R1[1],R2[1],R3[1],RP[1]);
if(BUG03>0) printf(" 03:R1,R2,R3,RP=%2.3f %2.3f %2.3f %2.3f \n",R1[2],R2[2],R3[2],RP[2]);
if(BUG04>0) printf(" 04:phid=%2.3f %2.3f %2.3f  \n",phid,ph2d,ph3d);
if(BUG04>0) printf(" 04:did  =%2.3f %2.3f %2.3f  \n",did,d2d,d3d);
if(BUG05>0) printf(" 05:V1=%2.3f %2.3f %2.3f  \n",V1[0],V1[1],V1[2]);
if(BUG05>0) printf(" 05:V2=%2.3f %2.3f %2.3f  \n",V2[0],V2[1],V2[2]);
if(BUG05>0) printf(" 05:V3=%2.3f %2.3f %2.3f  \n",V3[0],V3[1],V3[2]);
if(BUG06>0) printf(" 06:phi,the,psi=%2.3f %2.3f %2.3f  \n",ANGLE[0],ANGLE[1],ANGLE[2]);
if(BUG07>0) printf(" 07:PHIC,THEC,PSIC=%2.3f %2.3f %2.3f  \n",PHIC,THEC,PSIC);
if(BUG08>0) printf(" 08:epbc[0][j] = %2.3f %2.3f %2.3f \n",epbc[0][0],epbc[0][1],epbc[0][2]);
if(BUG08>0) printf(" 08:epbc[1][j] = %2.3f %2.3f %2.3f \n",epbc[1][0],epbc[1][1],epbc[1][2]);
if(BUG08>0) printf(" 08:epbc[2][j] = %2.3f %2.3f %2.3f \n",epbc[2][0],epbc[2][1],epbc[2][2]);
if(BUG09>0) printf(" 09:phic =%2.3f %2.3f %2.3f  \n",phi1c,phi2c,phi3c);
if(BUG09>0) printf(" 09:thec =%2.3f %2.3f %2.3f  \n",the1c,the2c,the3c);
if(BUG09>0) printf(" 09: dic  =%2.3f %2.3f %2.3f  \n",d1c,d2c,d3c);
if(BUG10>0) printf(" 10:phii=%2.3f %2.3f %2.3f  \n",phi1,phi2,phi3);
```

```
if(BUG10>0) printf(" 10:thei=%2.3f %2.3f %2.3f  \n",the1,the2,the3);
if(BUG10>0) printf(" 10:  di =%2.3f %2.3f %2.3f  \n",d1,d2,d3);
if(BUG11>0) printf(" 11:RPC =%2.3f %2.3f %2.3f  \n",RPC[0],RPC[1],RPC[2]);
if(BUG12>0) printf(" 12:LD1[j] =%2.3f %2.3f %2.3f  \n",LD1[0],LD1[1],LD1[2]);
if(BUG12>0) printf(" 12:LD2[j] =%2.3f %2.3f %2.3f  \n",LD2[0],LD2[1],LD2[2]);
if(BUG12>0) printf(" 12:LD3[j] =%2.3f %2.3f %2.3f  \n",LD3[0],LD3[1],LD3[2]);
if(BUG12>0) printf(" 12:delte[j] =%2.3f %2.3f %2.3f  \n",deltex,deltay,deltaz);

printf(" J= %3d\n",j);
scanf("%2d",&j);
return;
}

/* ..................................... Stert of Orientation Control Function ..................................... */

void orient(sdata)
struct sensor *sdata;

{
int i,j;

                                        /* Compute commanded euler matrix Sb to Sp     */
euler(PHIC,THEC,PSIC,epbc);
                                        /* Compute position vector of platform wrt base */
RPC[0] = DELR[0];
RPC[1] = DELR[1];
RPC[2] = DELR[2] - HEIGHT;
                                        /* Compute Leg vectors wrt Sb                                  */
R1b[0] = RPC[0] + RPLAT*epbc[0][0];
R1b[1] = RPC[1] + RPLAT*epbc[0][1];
R1b[2] = RPC[2] + RPLAT*epbc[0][2];

R2b[0] = RPC[0] + RPLAT*(SR3D2*epbc[1][0] - HALF*epbc[0][0]);
R2b[1] = RPC[1] + RPLAT*(SR3D2*epbc[1][1] - HALF*epbc[0][1]);
R2b[2] = RPC[2] + RPLAT*(SR3D2*epbc[1][2] - HALF*epbc[0][2]);

R3b[0] = RPC[0] + RPLAT*(-SR3D2*epbc[1][0] - HALF*epbc[0][0]);
R3b[1] = RPC[1] + RPLAT*(-SR3D2*epbc[1][1] - HALF*epbc[0][1]);
R3b[2] = RPC[2] + RPLAT*(-SR3D2*epbc[1][2] - HALF*epbc[0][2]);
                                        /* Compute Di vectors wrt Sb (Bi to Pi)        */
D1b[0] = R1b[0] - RBASE;
D1b[1] = R1b[1];
D1b[2] = R1b[2];

D2b[0] = R2b[0] + HALF*RBASE;
D2b[1] = R2b[1] - SR3D2*RBASE;
D2b[2] = R2b[2];
```

```
    D3b[0] = R3b[0] + HALF*BASE;
    D3b[1] = R3b[1] + SRD2*BASE;
    D3b[2] = R3b[2];

    d1c2 = .0;                                    /*Compute Leg length coord.      d1   */
    for(j=0;j<3;j++) d1c2 = d1c2 + D1b[j]*D1b[j];
    d2c2 = .0;
    for(j=0;j<3;j++) d2c2 = d2c2 + D2b[j]*D2b[j];
    d3c2 = .0;
    for(j=0;j<3;j++) d3c2 = d3c2 + D3b[j]*D3b[j];

    for(j=0;j<3;j++) L01[j] = D1b[j];             /* Compute phi & theta  motor angles  */

    matmpy(mk2,R2b,L02);                          /* Rotate to Leg Base frame           */
    matmpy(mk3,D3b,L03);

    d1c = sqrt(d1c2);
    d2c = sqrt(d2c2);
    d3c = sqrt(d3c2);

    phi1c = atan2(L01[1],d1c);
    the1c = asin(-L01[0]/sqrt(L01[0]*L01[0] + L01[2]*L01[2]));

    phi2c = atan2(L02[1],d2c);
    the2c = asin(-L02[0]/sqrt(L02[0]*L02[0] + L02[2]*L02[2]));

    phi3c = atan2(L03[1],d3c);
    the3c = asin(-L03[0]/sqrt(L03[0]*L03[0] + L03[2]*L03[2]));

/*.....*/
.....*/                                           /* Set output values   */

    sdata->d1     = d1c;
    sdata->the1   = the1c;
    sdata->phi1   = phi1c;
    sdata->d2     = d2c;
    sdata->the2   = the2c;
    sdata->phi2   = phi2c;
    sdata->d3     = d3c;
    sdata->the3   = the3c;
    sdata->phi3   = phi3c;

    return;
```

```
}
/*.....End of orient function.....*/

/* ..... Stert of Velocity Control Function ..... */

void controller(sdats)

struct sensor *sdats;

{
int j;
float det1,det2,det3;
                                        /* Transfer input dats from globel storage */
        d1    = sdate->d1;
        the1 = sdate->the1;
        phi1= sdata->phi1;
        d2    = sdats->d2;
        the2=  sdats->the2;
        phi2=  sdate->phi2;
        d3    = sdats->d3;
        the3 = sdats->the3;
        phi3 = sdats->phi3;
                                        /* Get desired linear & enguler velocities      */
        VEL[0]    = sdats->velx;    /* Input is assumed to be in Sb coord.           */
        VEL[1]    = sdata->vely;
        VEL[2]    = sdats->velz;
        prete[0] = sdate->wx;       /*Input is assumed to be in Sp coord.           */
        prete[1] = sdate->wy;
        prete[2] = sdate->wz;
                                        /* Compute sines & cosines      */
        sthe1 = sin(the1);
        cthe1 = cos(the1);
        sphi1 = sin(phi1);
        cphi1 = cos(phi1);

        sthe2 = sin(the2);
        cthe2 = cos(the2);
        sphi2 = sin(phi2);
        cphi2 = cos(phi2);

        sthe3 = sin(the3);
        cthe3= cos(the3);
        sphi3 = sin(phi3);
        cphi3 = cos(phi3);
```

```
                                        /* Compute R1,R2,R3,RF vectors */

R1[0] =  -d1*ctche1 + RBASE;
R1[1] =  d1*sthe1*sphi1;
R1[2] =  -d1*cthe1*sphi1;

R2[0] =  d2*((HALF*sthe2) - (SR3D2*cthe2*sphi2)) -  RBD2;
R2[1] =  d2*(-(SR3D2*sthe2) - (HALF*cthe2*sphi2)) + SR3D2*RBASE;
R2[2] =  -d2*cthe2*sphi2;

R3[0] =  d3*((HALF*sthe3) +( SR3D2*cthe3*sphi3)) - RBD2;
R3[1] =  d3*((SR3D2*sthe3) -  (HALF*cthe3*sphi3)) - SR3D2*RBASE;
R3[2] =  -d3*cthe3*cphi3;

for(j=0; j<3; j++) RF[j] = (1.0/3.0)*(R1[j] + R2[j] + R3[j]);

                                        /* Compute Platform origin position vector*/

for(j=0;j<3;j++) XP[j] = (R1[j] - RF[j])/RPLAT;
for(j=0;j<3;j++) YP[j] = (R2[j] - R1[j])*(SR3D3/RPLAT);
ZP[0] = (XP[1]*YP[0]) -  (XP[0]*YP[1]);
ZP[1] = (XP[2]*YP[0]) -  (XP[0]*YP[2]);
ZP[2] = (XP[0]*YP[1]) -  (XP[1]*YP[0]);

for(j=0;j<3;j++) epb[0][j] = XP[j];
for(j=0;j<3;j++) epb[1][j] = YP[j];
for(j=0;j<3;j++) epb[2][j] = ZP[j];

transpose(epb,ebp);                     /* Obtain euler matrix ebp[i][j]        */

matcpy(ebp,prate,ARATE);                /* Convert prate[i] to Sb coord.        */

for(j=0;j<3;j++) RP1[j] = R1[j] - RF[j];
for(j=0;j<3;j++) RP2[j] = R2[j] - RF[j];
for(j=0;j<3;j++) RP3[j] = R3[j] - RF[j];

                                        /* Compute linear velocity of legs      */

V1[0] = VEL[0] + (ARATE[1]*RP1[2] - ARATE[2]*RP1[1]);
V1[1] = VEL[1] + (ARATE[2]*RP1[0] - ARATE[0]*RP1[2]);
V1[2] = VEL[2] + (ARATE[0]*RP1[1] - ARATE[1]*RP1[0]);

V2[0] = VEL[0] + (ARATE[1]*RP2[2] - ARATE[2]*RP2[1]);
V2[1] = VEL[1] + (ARATE[2]*RP2[0] - ARATE[0]*RP2[2]);
V2[2] = VEL[2] + (ARATE[0]*RP2[1] - ARATE[1]*RP2[0]);

V3[0] = VEL[0] + (ARATE[1]*RP3[2] - ARATE[2]*RP3[1]);
V3[1] = VEL[1] + (ARATE[2]*RP3[0] - ARATE[0]*RP3[2]);
V3[2] = VEL[2] + (ARATE[0]*RP3[1] - ARATE[1]*RP3[0]);
```

```
                                        /* Compute rate transform matrices    */

e1[0][0] =  .0;
e1[1][0] =  d1*cthe1*cphi1;
e1[2][0] =  d1*cthe1*sphi1;
e1[0][1] = -d1*sthe1;
e1[1][1] = -d1*sthe1*sphi1;
e1[2][1] =  d1*sthe1*cphi1;
e1[0][2] = -sthe1;
e1[1][2] =  cthe1*sphi1;
e1[2][2] = -cthe1*cphi1;

e2[0][0] =  d2*(-SR3D2*cthe2*cphi2);
e2[1][0] =  d2*(   -HALF*cthe2*cphi2);
e2[2][0] =  d2*cthe2*sphi2;
e2[0][1] = -d2*((SR3D2*sthe2) + (SR3D2*sthe2*sphi2));
e2[1][1] = -d2*((-SR3D2*sthe2) +(HALF*sthe2*sphi2));
e2[2][1] =  d2*sthe2*cphi2;
e2[0][2] =  (( HALF*sthe3) -  (SR3D2*cthe3*sphi3));
e2[1][2] =  (-(SR3D2*sthe3) - (HALF*cthe3*sphi3)));
e2[2][2] =  -cthe3*cphi3;

e3[0][0] =  d3*(SR3D2*cthe3*cphi3);
e3[1][0] =  d3*(   -HALF*cthe3*cphi3);
e3[2][0] =  d3*cthe3*sphi3;
e3[0][1] = -d3*((HALF*cthe3) + (SR3D2*cthe3*sphi3));
e3[1][1] = -d3*((HALF*cthe3) + (HALF*cthe2*sphi3));
e3[2][1] =  d3*sthe3*cphi3;
e3[0][2] =  (( HALF*cthe3) + (SR3D2*cthe3*sphi3));
e3[1][2] =  ((SR3D2*sthe3) -  (HALF*cthe3*sphi3));
e3[2][2] =  -cthe3*cphi3;
                                        /* Form final matrices  */

matinv(e1,e1in,&det1);
matinv(e2,e2in,&det2);
matinv(e3,e3in,&det3);

                                        /* Compute motor rate commands  */
matmpy(e1in,V1,OUT1);
matmpy(e2in,V2,OUT2);
matmpy(e3in,V3,OUT3);

phid = OUT1[0];
phid = OUT1[0];
phid = OUT1[0];
did =  OUT1[2];
d2d =  OUT2[2];
d3d =  OUT3[2];

                                        /* Compute ONE SET of euler angles (of 12!)  */
```

```
    ANGLE[0] = atan2(epb[1][2],epb[2][2]);          /* This set is psi,theta,phi (in order) Sb to Sp    */
    ANGLE[1] = asin(-epb[0][2]);
    ANGLE[2] = atan2(epb[0][1],epb[0][0]);
/*.....
.....*/

                                                    /* Transfer Output Data */

    sdata->phidot = phid;
    sdata->ph2dot = ph2d;
    sdata->ph3dot = ph3d;

    sdata->d1dot  = d1d;
    sdata->d2dot  = d2d;
    sdata->d3dot  = d3d;
    memcpy(sbp.gripion,grip);
    sdata->xdelx  = RP[0] + grip[0];
    sdata->xdely  = RP[1] + grip[1];
    sdata->xdelz  = RP[2] + HEIGHT + grip[2];

    sdata->xpsi   = ANGLE[0];
    sdata->xtheta = ANGLE[1];
    sdata->xpsi   = ANGLE[2];

    return;
}
/*.....End of Velocity Control Fn.....*/

void quat(q1,q2,q3,q4, trans)

float q1,q2,q3,q4
float trans[3][3]
{

    trans[0][0] =  (q1*q1 + q2*q2 + q3*q3 + q4*q4);     /*Compute new transformation matrix    */
    trans[0][1] =  2.*(q2*q3 + q1*q4);
    trans[0][2] =  2.*(q2*q4 - q1*q3);
    trans[1][0] =  2.*(q2*q3 - q1*q4);
    trans[1][1] =  (q1*q1 - q2*q2 + q3*q3 - q4*q4);
    trans[1][2] =  2.*(q3*q4 + q1*q2);
    trans[2][0] =  2.*(q2*q4 + q1*q3);
    trans[2][1] =  2.*(q3*q4 - q1*q2);
    trans[2][2] =  (q1*q1 - q2*q2 - q3*q3 + q4*q4);
```

```
    return;
    }

/* ..........
.......... */

void euler(phi,the,psi,mat)

float phi,the,psi;
float mat[3][3];

{
    float sphi,cphi,sthe,cthe,spsi,cpsi;

    /* ..............  Euler Matrix Computation ..............*/
    /* Compute euler rotation matrix from Loc.Vert. to Body */

    sthe = sin(the);
    cthe = cos(the);
    spsi = sin(psi);
    cpsi = cos(psi);
    sphi = sin(phi);
    cphi = cos(phi);

    mat[0][0] = cthe*cpsi;
    mat[0][1] = cthe*spsi;
    mat[0][2] = -sthe;
    mat[1][0] = sphi*sthe*cpsi - cphi*spsi;
    mat[1][1] = sphi*sthe*spsi + cphi*cpsi;
    mat[1][2] = sphi*cthe;
    mat[2][0] = cphi*sthe*cpsi + sphi*spsi;
    mat[2][1] = cphi*sthe*spsi - sphi*cpsi;
    mat[2][2] = cphi*cthe;

    return;
}

/* ..........
.......... */

void matmpy(a,b,c)                  /* Matrix(3x3) times vector(1x3)*/
                                    /* Called from common           */
                                    /* float m[3][3] ;              */
                                    /*   float v[3] ;               */
                                    /*   matmpy(m,v,v)              */
    float a[3][3] ;
```

```
    float b[3] ;
    float c[3] ;

    {
    float t[3] ;

    t[0] = a[0][0]*b[0] + a[0][1]*b[1] + a[0][2]*b[2] ;
    t[1] = a[1][0]*b[0] + a[1][1]*b[1] + a[1][2]*b[2] ;
    t[2] = a[2][0]*b[0] + a[2][1]*b[1] + a[2][2]*b[2] ;

    c[0] = t[0] ;
    c[1] = t[1] ;
    c[2] = t[2] ;
    }
/*  ..................................... End "matmpy" Code ..................................*/

void matran(a,b,c)                  /* Matrix transposition multiply*/
                                    /* Matrix(3x3) times vector(1x3)*/
                                    /* Calling sequence:            */
                                    /*   float a[3][3] ;            */
                                    /*   float v[3] ;               */
                                    /*   matran(a,v,v)              */
    float a[3][3] ;
    float b[3] ;
    float c[3] ;

    {
    float t[3] ;

    t[0] = a[0][0]*b[0] + a[1][0]*b[1] + a[2][0]*b[2] ;
    t[1] = a[0][1]*b[0] + a[1][1]*b[1] + a[2][1]*b[2] ;
    t[2] = a[0][2]*b[0] + a[1][2]*b[1] + a[2][2]*b[2] ;

    c[0] = t[0] ;
    c[1] = t[1] ;
    c[2] = t[2] ;
    }
/*  ..................... End "matran" Code ..................................*/

void matinv(a,b,det)                /* Matrix (3x3) Inverse & Determinant)  */

                                    /* Calling sequence:            */
                                    /*   float m[3][3] ;            */
                                    /*   float n[3][3] ;            */
                                    /*   float *det                 */
```

```
/*   matinv(m,n,*det)   */

                                                                    */
/* Cramer's Rule used to compute inverse.                             */
/* Inverse of m to n (with determinant returned always)               */
/* If det "smaller" than "tiny", inverse not returned                 */

float a[3][3] ;
float b[3][3] ;
float *det ;
{
*det   =  a[0][0] * (a[1][1]*a[2][2] - a[1][2]*a[2][1])
        + a[1][0] * (a[2][1]*a[0][2] - a[0][1]*a[2][2])
        + a[2][0] * (a[0][1]*a[1][2] - a[1][1]*a[0][2]),

if (fabs(*det)<TINY) return;

temp = 1.0/(*det);

b[0][0] =  temp * (a[1][1]*a[2][2] - a[1][2]*a[2][1]),
b[1][0] = -temp * (a[1][0]*a[2][2] - a[1][2]*a[2][0]),
b[2][0] =  temp * (a[1][0]*a[2][1] - a[1][1]*a[2][0]),

b[0][1] = -temp * (a[0][1]*a[2][2] - a[0][2]*a[2][1]),
b[1][1] =  temp * (a[0][0]*a[2][2] - a[0][2]*a[2][0]),
b[2][1] = -temp * (a[0][0]*a[2][1] - a[0][1]*a[2][0]),

b[0][2] =  temp * (a[0][1]*a[1][2] - a[0][2]*a[1][1]),
b[1][2] = -temp * (a[0][0]*a[1][2] - a[0][2]*a[1][0]),
b[2][2] =  temp * (a[0][0]*a[1][1] - a[0][1]*a[1][0]),
}

/*   ..... End "matinv" Code ..........................................*/

void mmult(a,b,c)
                        /* Matrix(3x3) times matrix(3x3)*/
                        /* Calling sequence:            */
                        /*  float a[3][3] ;             */
                        /*  float b[3][3] ;             */
                        /*  float c[3][3] ;             */
                        /*  mmult(a,b,c) ;              */
                        /*  (a)x(b) -> (c)              */
float a[3][3] ;
float b[3][3] ;
float c[3][3] ;
{
c[0][0] = a[0][0]*b[0][0] + a[0][1]*b[1][0] + a[0][2]*b[2][0] ;
```

```
c[1][0] = a[1][0]*b[0][0] + a[1][1]*b[1][0] + a[1][2]*b[2][0] ;
c[2][0] = a[2][0]*b[0][0] + a[2][1]*b[1][0] + a[2][2]*b[2][0] ;

c[0][1] = a[0][0]*b[0][1] + a[0][1]*b[1][1] + a[0][2]*b[2][1] ;
c[1][1] = a[1][0]*b[0][1] + a[1][1]*b[1][1] + a[1][2]*b[2][1] ;
c[2][1] = a[2][0]*b[0][1] + a[2][1]*b[1][1] + a[2][2]*b[2][1] ;

c[0][2] = a[0][0]*b[0][2] + a[0][1]*b[1][2] + a[0][2]*b[2][2] ;
c[1][2] = a[1][0]*b[0][2] + a[1][1]*b[1][2] + a[1][2]*b[2][2] ;
c[2][2] = a[2][0]*b[0][2] + a[2][1]*b[1][2] + a[2][2]*b[2][2] ;
}
/*  ..... End "vmult" Code .....*/

void transpose(a,b)

                    /* Matrix(3x3) transpose to matrix(3x3)*/
                    /* Calling sequence:                   */
                    /*   float a[3][3] ;                   */
                    /*   float b[3][3] ;                   */
                    /*   transpose(a,b) ;                  */
                    /*     (a) -> (b)                      */

float a[3][3] ;
float b[3][3] ;
{
b[0][0] = a[0][0] ;
b[1][0] = a[0][1] ;
b[2][0] = a[0][2] ;
b[0][1] = a[1][0] ;
b[1][1] = a[1][1] ;
b[2][1] = a[1][2] ;
b[0][2] = a[2][0] ;
b[1][2] = a[2][1] ;
b[2][2] = a[2][2] ;
}
/*  ..... End "vmult" Code .....*/
```

```
#include "../include/mem_map.h"
#include "../include/dtok.h"
#include "../include/hc4.h"

#define  extern
#include "../include/vp.h"
#undef   extern

#define DOSP  asm("     bset    #05,$fffb0001");

unsigned long cnt4[3];
double lim[3];
struct sensor hc;
double phic,thac,psic,xc,yc,zc,pz,PZ;

/*-------------------------------------------------------------------------*/
myfunc50hz()
{
static int k25 = 0;
static int k10 = 1;
static int k05 = 2;
static int k02 = 3;
static int k01 = 4;

 /* asm("     bset    #05,$fffb0001"); */
asm("     bclr    #05,$fffb0001");

k25 = (k25 + 1) % 2;
k10 = (k10 + 1) % 5;
k05 = (k05 + 1) % 10;
k02 = (k02 + 1) % 25;
k01 = (k01 + 1) % 50;

do50hz();

if (k25 == 0)
   {
   }

if (k10 == 0)
   {
   }

if (k05 == 0)
   {
   }
```

```
    if (k02 == 0)
        {
        }

    if (k01 == 0)
        {
        }

    /* asm("      bclr    #85,$fff880001"); */
    }

/*-------------------------------------------------------------------------*/
inteyfunc50hz()
{
vp.igo = INT_OFF;
vp.mod = POS_MODE;
vp.dof = THREE_DOF;
vp.bol = BOWL_OFF;
vp.kp  = 3.0;
vp.kr  = 15.0;

MAX_FORCE  =  30.0;
MAX_MOMENT = 200.0;

/* initialize fts, ioo, atod, and dcos */

vio_init(BIM_ADDR);
atod_init(IO_LEVEL,VME_LEVEL,VECTOR);
dcos_init();

card[0] = dcos_define(A_BASE_ADDR,A_RANGE);
card[1] = dcos_define(B_BASE_ADDR,B_RANGE);
card[2] = atod_define(C_BASE_ADDR,C_RANGE,C_CHANNELS);

/* assign channels and cards for pots and tachs */

leg1.lin.rat.chn =  0; leg1.lin.rat.crd = 2;
leg1.lin.pos.chn =  1; leg1.lin.pos.crd = 2;
leg1.rad.pos.chn =  2; leg1.rad.pos.crd = 2;
leg1.tan.rat.chn =  3; leg1.tan.rat.crd = 2;
leg1.tan.pos.chn =  4; leg1.tan.pos.crd = 2;

leg2.lin.rat.chn =  5; leg2.lin.rat.crd = 2;
leg2.lin.pos.chn =  6; leg2.lin.pos.crd = 2;
leg2.rad.pos.chn =  7; leg2.rad.pos.crd = 2;
leg2.tan.rat.chn =  8; leg2.tan.rat.crd = 2;
leg2.tan.pos.chn =  9; leg2.tan.pos.crd = 2;
```

```
leg3.lin.rat.chn = 10; leg3.lin.rat.crd = 2;
leg3.lin.pos.chn = 11; leg3.lin.pos.crd = 2;
leg3.rad.pos.chn = 12; leg3.rad.pos.crd = 2;
leg3.tan.rat.chn = 13; leg3.tan.rat.crd = 2;
leg3.tan.pos.chn = 14; leg3.tan.pos.crd = 2;

/* assign channels and cards for motor drivers */

leg1.lin.mot.chn =  1; leg1.lin.mot.crd = 0;
leg1.tan.mot.chn =  2; leg1.tan.mot.crd = 0;

leg2.lin.mot.chn =  3; leg2.lin.mot.crd = 0;
leg2.tan.mot.chn =  4; leg2.tan.mot.crd = 0;

leg3.lin.mot.chn =  1; leg3.lin.mot.crd = 1;
leg3.tan.mot.chn =  2; leg3.tan.mot.crd = 1;

/* zero integrators for rate and position loops */

leg1.lin.rat.ier = 0.0;
leg1.tan.rat.ier = 0.0;

leg2.lin.rat.ier = 0.0;
leg2.tan.rat.ier = 0.0;

leg3.lin.rat.ier = 0.0;
leg3.tan.rat.ier = 0.0;

/* set motor driver outputs to 0.0v */

dtoa_write(card[leg1.lin.mot.crd],leg1.lin.mot.chn,VOLTAGE,0.0);
dtoa_write(card[leg1.tan.mot.crd],leg1.tan.mot.chn,VOLTAGE,0.0);

dtoa_write(card[leg2.lin.mot.crd],leg2.lin.mot.chn,VOLTAGE,0.0);
dtoa_write(card[leg2.tan.mot.crd],leg2.tan.mot.chn,VOLTAGE,0.0);

dtoa_write(card[leg3.lin.mot.crd],leg3.lin.mot.chn,VOLTAGE,0.0);
dtoa_write(card[leg3.tan.mot.crd],leg3.tan.mot.chn,VOLTAGE,0.0);
}

/*-------------------------------------------------------------------------*/
double lim(x,min,max)
double x,min,max;
{
if (x < min) return(min);
if (x > max) return(max);
```

```
return(x);
}

/*-------------------------------------------------------------------------*/
ds50hx()
{
etod_read(&ardlleg1.lin.rat.crd),leg1.lin.rat.chn,0x0c,&leg1.lin.rat.val)
etod_read(&ardlleg1.lin.pos.crd),leg1.lin.pos.chn,0x0c,&leg1.lin.pos.val)
etod_read(&ardlleg1.tan.rat.crd),leg1.tan.rat.chn,0x0c,&leg1.tan.rat.val)
etod_read(&ardlleg1.tan.pos.crd),leg1.tan.pos.chn,0x0c,&leg1.tan.pos.val)
etod_read(&ardlleg1.rad.pos.crd),leg1.rad.pos.chn,0x0c,&leg1.rad.pos.val)

etod_read(&ardlleg2.lin.rat.crd),leg2.lin.rat.chn,0x0c,&leg2.lin.rat.val)
etod_read(&ardlleg2.lin.pos.crd),leg2.lin.pos.chn,0x0c,&leg2.lin.pos.val)
etod_read(&ardlleg2.tan.rat.crd),leg2.tan.rat.chn,0x0c,&leg2.tan.rat.val)
etod_read(&ardlleg2.tan.pos.crd),leg2.tan.pos.chn,0x0c,&leg2.tan.pos.val)
etod_read(&ardlleg2.rad.pos.crd),leg2.rad.pos.chn,0x0c,&leg2.rad.pos.val)

etod_read(&ardlleg3.lin.rat.crd),leg3.lin.rat.chn,0x0c,&leg3.lin.rat.val)
etod_read(&ardlleg3.lin.pos.crd),leg3.lin.pos.chn,0x0c,&leg3.lin.pos.val)
etod_read(&ardlleg3.tan.rat.crd),leg3.tan.rat.chn,0x0c,&leg3.tan.rat.val)
etod_read(&ardlleg3.tan.pos.crd),leg3.tan.pos.chn,0x0c,&leg3.tan.pos.val)
etod_read(&ardlleg3.rad.pos.crd),leg3.rad.pos.chn,0x0c,&leg3.rad.pos.val)

/* convert tangential meas. to rad and sec, right hand rule, thumb out */

ho.phi1 = leg1.tan.pos.val*TAN_POS_SF;
ho.phi2 = leg2.tan.pos.val*TAN_POS_SF;
ho.phi3 = leg3.tan.pos.val*TAN_POS_SF;

/* convert radial meas. to rad and sec, positive leg top in */

ho.the1 = -leg1.rad.pos.val*RAD_POS_SF;
ho.the2 = -leg2.rad.pos.val*RAD_POS_SF;
ho.the3 = -leg3.rad.pos.val*RAD_POS_SF;

/* convert linear meas. to inches, positive leg extended */

ho.d1 = -leg1.lin.pos.val*LIN_POS_SF + LIN_POS_OFF;
ho.d2 = -leg2.lin.pos.val*LIN_POS_SF + LIN_POS_OFF;
ho.d3 = -leg3.lin.pos.val*LIN_POS_SF + LIN_POS_OFF;

/* convert linear tachs to positive leg extending */

leg1.lin.rat.val = -leg1.lin.rat.val;
leg2.lin.rat.val = -leg2.lin.rat.val;
leg3.lin.rat.val = -leg3.lin.rat.val;
```

```
/* controller */

hc.velx = 0.0;
hc.vely = 0.0;
hc.velz = 0.0;

hc.wx = 0.0;
hc.wy = 0.0;
hc.wz = 0.0;

if (vp.bol == BOWL_ON)
    {
    px = -lim(vp.mx/MAX_MOMENT,-1.0,1.0);
    py = -lim(vp.mz/MAX_MOMENT,-1.0,1.0);
    bowl(px,py,&xc,&yc,&zc,&phic,&thec,&psic);

    hc.velx = vp.kp*(xc - hc.delx);
    hc.vely = vp.kp*(yc - hc.dely);
    hc.velz = vp.kp*(zc - (LIN_POS_OFF + hc.delz));

    hc.wx = vp.kp*(phic - hc.phi);
    hc.wy = vp.kp*(thec - hc.the);
    hc.wz = vp.kp*(psic - hc.psi)
    }
if (vp.bol == BOWL_OFF)
    {
    if (vp.mod == RATE_MODE)
        {
        xc = 0.0;
        yc = 0.0;
        zc = 0.0;
        if (vp.dof == SIX_DOF)
            {
            xc = lim( vp.fx/MAX_FORCE,-MAX_TRANS,MAX_TRANS);
            yc = lim( vp.fz/MAX_FORCE,-MAX_TRANS,MAX_TRANS);
            zc = lim(-vp.fz/MAX_FORCE,-MAX_TRANS,MAX_TRANS);
            }
        hc.velx = vp.kp*(xc - hc.delx);
        hc.vely = vp.kp*(yc - hc.dely);
        hc.velz = vp.kp*(zc - (LIN_POS_OFF + hc.delz));

        phic = lim( vp.my/MAX_MOMENT,-MAX_ANGLE,MAX_ANGLE);
        thec = lim( vp.mz/MAX_MOMENT,-MAX_ANGLE,MAX_ANGLE);
        psic = lim(-vp.mx/MAX_MOMENT,-MAX_ANGLE,MAX_ANGLE);

        hc.wx = vp.kp*(phic - hc.phi);
```

```
        hc.wy = vp.kp*(theo - hc.theta);
        hc.wz = vp.kp*(psio - hc.psi);
        }
    if (vp.mod == POS_MODE)
        {
        if (vp.dof == SIX_DOF)
            {
                if (vp.fy >  FORCE_DBAND) hc.vely =  1.0;
                if (vp.fy <  -FORCE_DBAND) hc.vely = -1.0;
                if (vp.fz >  FORCE_DBAND) hc.velz =  1.0;
                if (vp.fz <  -FORCE_DBAND) hc.velz = -1.0;
                if (vp.fs >  FORCE_DBAND) hc.vels =  0.5;
                if (vp.fs <  -FORCE_DBAND) hc.vels = -0.5;

                if (vp.my >  MOM_DBAND) hc.wx =  0.3;
                if (vp.my <  -MOM_DBAND) hc.wx = -0.3;
                if (vp.mz >  MOM_DBAND) hc.wy =  0.3;
                if (vp.mz <  -MOM_DBAND) hc.wy = -0.3;
                if (vp.ms >  MOM_DBAND) hc.ws =  0.3;
                if (vp.ms <  -MOM_DBAND) hc.ws = -0.3;

                if (hc.delx >  1.5*MAX_TRANS && hc.velx > 0.0) (hc.velx = 0.0/DOIF)
                if (hc.delx <  -1.5*MAX_TRANS && hc.velx < 0.0) (hc.velx = 0.0/DOIF)
                if (hc.dely >  1.5*MAX_TRANS && hc.vely > 0.0) (hc.vely = 0.0/DOIF)
                if (hc.dely <  -1.5*MAX_TRANS && hc.vely < 0.0) (hc.vely = 0.0/DOIF)

                if (hc.phi   >  1.0*MAX_ANGLE && hc.wx > 0.0) (hc.wx = 0.0/DOIF)
                if (hc.phi   <  -1.0*MAX_ANGLE && hc.wx < 0.0) (hc.wx = 0.0/DOIF)
                if (hc.theta >  1.0*MAX_ANGLE && hc.wy > 0.0) (hc.wy = 0.0/DOIF)
                if (hc.theta <  -1.0*MAX_ANGLE && hc.wy < 0.0) (hc.wy = 0.0/DOIF)
                if (hc.psi   >  2.0*MAX_ANGLE && hc.ws > 0.0) (hc.ws = 0.0/DOIF)
                if (hc.psi   <  -2.0*MAX_ANGLE && hc.ws < 0.0) (hc.ws = 0.0/DOIF)
            }

        controller(ihc);

        leg1.tan.rat.cmd = V_PER_RPS*ho.phidot;
        leg2.tan.rat.cmd = V_PER_RPS*ho.ph2dot;
        leg3.tan.rat.cmd = V_PER_RPS*ho.ph3dot;

        leg1.lin.rat.cmd = V_PER_IPS*ho.didot;
        leg2.lin.rat.cmd = V_PER_IPS*ho.d2dot;
        leg3.lin.rat.cmd = V_PER_IPS*ho.d3dot;

        /* legl tangential rate loop */
```

```
leg1.tan.rat.err = leg1.tan.rat.cmd - leg1.tan.rat.val;
if (vp.igo == INT_ON)
    leg1.tan.rat.ior = lim(leg1.tan.rat.ior +
                           DELK*leg1.tan.rat.err,-INT_LIM,INT_LIM);
leg1.tan.mot.val = lim(vp.kr*leg1.tan.rat.ior,-VOLT_LIM,VOLT_LIM);

/* leg2 tangential rate loop */

leg2.tan.rat.err = leg2.tan.rat.cmd - leg2.tan.rat.val;
if (vp.igo == INT_ON)
    leg2.tan.rat.ior = lim(leg2.tan.rat.ior +
                           DELK*leg2.tan.rat.err,-INT_LIM,INT_LIM);
leg2.tan.mot.val = lim(vp.kr*leg2.tan.rat.ior,-VOLT_LIM,VOLT_LIM);

/* leg3 tangential rate loop */

leg3.tan.rat.err = leg3.tan.rat.cmd - leg3.tan.rat.val;
if (vp.igo == INT_ON)
    leg3.tan.rat.ior = lim(leg3.tan.rat.ior +
                           DELK*leg3.tan.rat.err,-INT_LIM,INT_LIM);
leg3.tan.mot.val = lim(vp.kr*leg3.tan.rat.ior,-VOLT_LIM,VOLT_LIM);

/* leg1 linear rate loop */

leg1.lin.rat.err = leg1.lin.rat.cmd - leg1.lin.rat.val;
if (vp.igo == INT_ON)
    leg1.lin.rat.ior = lim(leg1.lin.rat.ior +
                           DELK*leg1.lin.rat.err,-INT_LIM,INT_LIM);
leg1.lin.mot.val = lim(vp.kr*leg1.lin.rat.ior,-VOLT_LIM,VOLT_LIM);

/* leg2 linear rate loop */

leg2.lin.rat.err = leg2.lin.rat.cmd - leg2.lin.rat.val;
if (vp.igo == INT_ON)
    leg2.lin.rat.ior = lim(leg2.lin.rat.ior +
                           DELK*leg2.lin.rat.err,-INT_LIM,INT_LIM);
leg2.lin.mot.val = lim(vp.kr*leg2.lin.rat.ior,-VOLT_LIM,VOLT_LIM);

/* leg3 linear rate loop */

leg3.lin.rat.err = leg3.lin.rat.cmd - leg3.lin.rat.val;
if (vp.igo == INT_ON)
    leg3.lin.rat.ior = lim(leg3.lin.rat.ior +
                           DELK*leg3.lin.rat.err,-INT_LIM,INT_LIM);
leg3.lin.mot.val = lim(vp.kr*leg3.lin.rat.ior,-VOLT_LIM,VOLT_LIM);

/* actuator commands */
```

```
dtoa_write(card[leg1.tan.mot.crd],leg1.tan.mot.ohm,VOLTAGE,leg1.tan.mot.val);
dtoa_write(card[leg1.lin.mot.crd],leg1.lin.mot.ohm,VOLTAGE,leg1.lin.mot.val);

dtoa_write(card[leg2.tan.mot.crd],leg2.tan.mot.ohm,VOLTAGE,leg2.tan.mot.val);
dtoa_write(card[leg2.lin.mot.crd],leg2.lin.mot.ohm,VOLTAGE,leg2.lin.mot.val);

dtoa_write(card[leg3.tan.mot.crd],leg3.tan.mot.ohm,VOLTAGE,leg3.tan.mot.val);
dtoa_write(card[leg3.lin.mot.crd],leg3.lin.mot.ohm,VOLTAGE,leg3.lin.mot.val);
}
```

```
/* Changes: 12/21/89 DJL  Moved #defines for constants and typedef for  */
/*                        sensor data structure to hc4.h.  "If"ed out   */
/*                        main.  Replaced #include for math.h with      */
/*                        mymath.h.                                     */

/* ......................Velocity Control Subroutine and Main Driver ..... */

/*      Project: Virtual Pivot Hand Controler (IR&D F4925-3000-2822)          */

/*       Programmed By:          William C. Marshall
                                 Systems & Research Center
                                 Honeywell, Inc.
                                 3660 Technology Drive
                                 Minneapolis, MN 55418
                                 (612) 782 - 7266
                                 29 Nov 1989
                                                                          */

/*      Description:    Theory of the C-Language code of this subprogram is
                        documented in the technical memo "Adaptable 6-DOF
                        Virtual Pivot Handcontroller: System Equations",
                        by W.C. Marshall, Dec 1989.                       */



/* ..................................... Start of Global Declarations ..... */

#include "../include/mymath.h"
#include "../include/hc4.h"
#include <stdio.h>

                        /* List of functions used by "main" */
void controller();
void orient();
void quat();
void euler();
void matmpy();
void matran();
void matinv();
void transpose();
void mmult();

                                        /* MISCELANEOUS */

static float epb[3][3];         /* Euler transformation matrix (Base-To-Platform)   */
static float ebp[3][3];         /* Euler transformation matrix (Platform-To-Base)   */
```

```
static float e1b[3][3];        /* Leg #1 euler matrix Sb to L1                    */
static float e2b[3][3];        /* Leg #2 euler matrix Sb to L2                    */
static float e3b[3][3];        /* Leg #3 euler matrix Sb to L3                    */

static float e1[3][3];         /* Leg #1 angular rate transform matrix            */
static float e2[3][3];         /* Leg #2 angular rate transform matrix            */
static float e3[3][3];         /* Leg #3 angular rate transform matrix            */
static float e1in[3][3];       /* Inverse of e1 matrix                            */
static float e2in[3][3];       /* Inverse of e2 matrix                            */
static float e3in[3][3];       /* Inverse of e3 matrix                            */

                               /* KEY PARAMETER LIST DECLARATIONS */

static float ANGLE[3];              /*  Euler angles phi,theta,psi wrt Sb    */
static float ARATE[3];              /*  Platform rates Wx,Wy,Wz in Sb        */
static float RP[3];                 /* Platform oenterposition wrt Sb        */
static float VEL[3];                /* Platform velocity wrt Sb                        */
static float R1[3];                 /* Position of Leg #1 at top in Sb                 */
static float R2[3];                 /* Position of Leg #2 at top in Sb                 */
static float R3[3];                 /* Position of Leg #3 at top in Sb                 */
static float V1[3];                 /* Velocity of Leg#1 at top in Sb                  */
static float V2[3];                 /* Velocity of Leg#2 at top in Sb                  */
static float V3[3];                 /* Velocity of Leg#3 at top in Sb                  */
static float RP1[3];                /* Rel. position of Leg #1 wrt RP[i]    */
static float RP2[3];                /* Rel. position of Leg #2 wrt RP[i]    */
static float RP3[3];                /* Rel. position of Leg #3 wrt RP[i]    */
static float XP[3];                 /* Platform Sp unit vector coordinates  */
static float YP[3];                 /* Platform Sp unit vector coordinates  */
static float ZP[3];                 /* Platform Sp unit vector coordinates  */
static float OUT1[3];               /* Motor rates for Leg #1                          */
static float OUT2[3];               /* Motor rates for Leg #2                          */
static float OUT3[3];               /* Motor rates for Leg #3                          */

static float PHIC;                        /* Commanded initial roll orientation    */
static float THEC;                  /* Commanded initial pitch orientation  */
static float PSIC;                        /* Commanded initial yaw orientation     */
static float DELR[3];               /* Commanded initial position vector     */
static float RPC[3];                /* Platform position vector wrt Sb       */
static float R1b[3];                /*Computed Leg vectors in Sb             */
static float R2b[3];                /*Computed Leg vectors in Sb             */
static float R3b[3];                /*Computed Leg vectors in Sb             */
static float D1b[3];                /*Computed Leg vectors in Sb at B1       */
static float D2b[3];                /*Computed Leg vectors in Sb at B2       */
static float D3b[3];                /*Computed Leg vectors in Sb at B3       */
static float _D1[3],_D2[3],_D3[3];  /*Computed Leg vectors in SLi at Bi      */
static float epbc[3][3];            /* Computed euler matrix Sb to Sp        */
```


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```
static float ak2[3][3],ak3[3][3];        /* Constant matrix kb to Ki for Di[3]  */
static float temp[3];                    /* Temporary vector storage            */

static float d1,d2,d3;
static float the1,the2,the3;
static float phi1,phi2,phi3;
static float dthe1,dthe2,dthe3;
static float dthe1,dthe2,dthe3;
static float sphi1,sphi2,sphi3;
static float sphi1,sphi2,sphi3;
static float dphi1,dphi2,dphi3;
static float ddthe1,ddthe2,ddthe3;
static float ddthe1,ddthe2,ddthe3;
static float ddd1,ddd2,ddd3;
static float detemp,temp;
static float d1c,d2c,d3c,dic2,d2c2,d3c2;
static float phi1c,phi2c,phi3c;
static float dthe1c,dthe2c,dthe3c;
static float vtemp[3][3];
static float pval[3];

/* ..........DEBUGING DECLARATIONS..........*/

static int BUG00 = 1;   /* =1 means set IC from pos. & angles   */
static int BUG01 = 1;   /* =1 means print epb[i][j]             */
static int BUG02 = 0;   /* =1 means print ebp[i][j]             */
static int BUG03 = 0;   /* =1 means print R1,R2,R3,RP           */
static int BUG04 = 1;   /* =1 means print phi's & dif outputs   */
static int BUG05 = 1;   /* =1 means print Vi vectors            */
static int BUG06 = 1;   /* =1 means print euler angles          */
static int BUG07 = 1;   /* =1 means print IC attitude commands*/
static int BUG08 = 1;   /* =1 means print euler matrix result */
static int BUG09 = 1;   /* =1 means print dic,dic2, phic        */
static int BUG10 = 1;   /* =1 means print d1,the1, phi1         */
static int BUG11 = 0;   /* =1 means print RPC[j]                */
static int BUG12 = 1;   /* =1means print Di[j]                  */

/* ************************************************************ */

#if 0
main()

{
int j;

struct sensor sdata;
j = 0;
```

```
                                                    /* Set default values   */
sdata.dl    =  4.0;
sdata.the1  =  .0;
sdata.phi1  =  .0;
sdata.d2    =  4.0;
sdata.the2  =  .0;
sdata.phi2  =  .0;
sdata.d3    =  4.0;
sdata.the3  =  .0;
sdata.phi3  =  .0;
sdata.velx  =  .0;
sdata.vely  =  .0;
sdata.velz  =  .0;
sdata.wx    =  .0;
sdata.wy    =  .0;
sdata.wz    =  .0;
                                                    /* Set default commands if to be used   */
DELR[0] = .0;
DELR[1] = .0;
DELR[2] = .0;
PHIC = .1;
THEC = .0;
PSIC =  .0;

                                                    /* Use position & angle vectors   */
if(BUG00>0) orient(&sdata);
                                                    /* Invoke motor velocity control */
controller(&sdata);


if(BUG01>0) printf(" 01:epb[0][j] = %2.3f %2.3f %2.3f \n",epb[0][0],epb[0][1],epb[0][2]);
if(BUG01>0) printf(" 01:epb[1][j] = %2.3f %2.3f %2.3f \n",epb[1][0],epb[1][1],epb[1][2]);
if(BUG01>0) printf(" 01:epb[2][j] = %2.3f %2.3f %2.3f \n",epb[2][0],epb[2][1],epb[2][2]);
if(BUG02>0) printf(" 02:ebp[0][j] = %2.3f %2.3f %2.3f \n",ebp[0][0],ebp[0][1],ebp[0][2]);
if(BUG02>0) printf(" 02:ebp[1][j] = %2.3f %2.3f %2.3f \n",ebp[1][0],ebp[1][1],ebp[1][2]);
if(BUG02>0) printf(" 02:ebp[2][j] = %2.3f %2.3f %2.3f \n",ebp[2][0],ebp[2][1],ebp[2][2]);
if(BUG03>0) printf(" 03:R1,R2,R3,RP=%2.3f %2.3f %2.3f %2.3f \n",R1[0],R2[0],R3[0],RP[0]);
if(BUG03>0) printf(" 03:R1,R2,R3,RP=%2.3f %2.3f %2.3f %2.3f \n",R1[1],R2[1],R3[1],RP[1]);
if(BUG03>0) printf(" 03:R1,R2,R3,RP=%2.3f %2.3f %2.3f %2.3f \n",R1[2],R2[2],R3[2],RP[2]);
if(BUG04>0) printf(" 04:phid=%2.3f %2.3f %2.3f  \n",phid,ph2d,ph3d);
if(BUG04>0) printf(" 04:did  =%2.3f %2.3f %2.3f  \n",did,d2d,d3d);
if(BUG05>0) printf(" 05:V1=%2.3f %2.3f %2.3f  \n",V1[0],V1[1],V1[2]);
if(BUG05>0) printf(" 05:V2=%2.3f %2.3f %2.3f  \n",V2[0],V2[1],V2[2]);
if(BUG05>0) printf(" 05:V3=%2.3f %2.3f %2.3f  \n",V3[0],V3[1],V3[2]);
if(BUG06>0) printf(" 06:phi,the,psi=%2.3f %2.3f %2.3f  \n",ANGLE[0],ANGLE[1],ANGLE[2]);
if(BUG07>0) printf(" 07:PHIC,THEC,PSIC=%2.3f %2.3f %2.3f  \n",PHIC,THEC,PSIC);
```

```
if(BUG08>0) printf(" 08:epbo[0][j] = %2.3f %2.3f %2.3f \n",epbo[0][0],epbo[0][1],epbo[0][2]);
if(BUG08>0) printf(" 08:epbo[1][j] = %2.3f %2.3f %2.3f \n",epbo[1][0],epbo[1][1],epbo[1][2]);
if(BUG08>0) printf(" 08:epbo[2][j] = %2.3f %2.3f %2.3f \n",epbo[2][0],epbo[2][1],epbo[2][2]);
if(BUG09>0) printf(" 09:phic =%2.3f %2.3f %2.3f  \n",phi1c,phi2c,phi3c);
if(BUG09>0) printf(" 09:thec =%2.3f %2.3f %2.3f  \n",the1c,the2c,the3c);
if(BUG09>0) printf(" 09: dic  =%2.3f %2.3f %2.3f  \n",d1c,d2c,d3c);
if(BUG10>0) printf(" 10:phii=%2.3f %2.3f %2.3f  \n",phi1,phi2,phi3);
if(BUG10>0) printf(" 10:thei=%2.3f %2.3f %2.3f  \n",the1,the2,the3);
if(BUG10>0) printf(" 10:  di =%2.3f %2.3f %2.3f  \n",di,d2,d3);
if(BUG11>0) printf(" 11:RPC =%2.3f %2.3f %2.3f  \n",RPC[0],RPC[1],RPC[2]);
if(BUG12>0) printf(" 12:D1[j] =%2.3f %2.3f %2.3f  \n",_D1[0],_D1[1],_D1[2]);
if(BUG12>0) printf(" 12:D2[j] =%2.3f %2.3f %2.3f  \n",_D2[0],_D2[1],_D2[2]);
if(BUG12>0) printf(" 12:D3[j] =%2.3f %2.3f %2.3f  \n",_D3[0],_D3[1],_D3[2]);

printf(" J= %3d\n",j);
scanf("%2d",&j);
return;
}
#endif

/* ..................................... Start of Orientation Control Function ..................................... */

void orient(sdata)
struct sensor *sdata;

{
int i,j;

                                        /* Compute commanded euler matrix Sb to Sp      */
euler(PHIC,THEC,PSIC,epbo);
                                        /* Compute position vector of platform wrt base */
RPC[0] = DELR[0];
RPC[1] = DELR[1];
RPC[2] = DELR[2] - HEIGHT;

                                        /* Compute Leg vectors wrt Sb                                  */
R1b[0] = RPC[0] + RPLAT*epbo[0][0];
R1b[1] = RPC[1] + RPLAT*epbo[0][1];
R1b[2] = RPC[2] + RPLAT*epbo[0][2];

R2b[0] = RPC[0] + RPLAT*(SR3D2*epbo[1][0] - HALF*epbo[0][0]);
R2b[1] = RPC[1] + RPLAT*(SR3D2*epbo[1][1] - HALF*epbo[0][1]);
R2b[2] = RPC[2] + RPLAT*(SR3D2*epbo[1][2] - HALF*epbo[0][2]);

R3b[0] = RPC[0] + RPLAT*(-SR3D2*epbo[1][0] - HALF*epbo[0][0]);
R3b[1] = RPC[1] + RPLAT*(-SR3D2*epbo[1][1] - HALF*epbo[0][1]);
R3b[2] = RPC[2] + RPLAT*(-SR3D2*epbo[1][2] - HALF*epbo[0][2]);
                                        /* Compute Di vectors wrt Sb (Bi to Pi)         */
```

```
D1b[0] = R1b[0] - RBASE;
D1b[1] = R1b[1];
D1b[2] = R1b[2];

D2b[0] = R2b[0] + HALF*RBASE;
D2b[1] = R2b[1] - SR3D2*RBASE;
D2b[2] = R2b[2];

D3b[0] = R3b[0] + HALF*RBASE;
D3b[1] = R3b[1] + SR3D2*RBASE;
D3b[2] = R3b[2];

                                        /*Compute Leg length coord.      di  */

d1c2 = .0;
for(j=0;j<3;j++) d1c2 = d1c2 + D1b[j]*D1b[j];
d2c2 = .0;
for(j=0;j<3;j++) d2c2 = d2c2 + D2b[j]*D2b[j];
d3c2 = .0;
for(j=0;j<3;j++) d3c2 = d3c2 + D3b[j]*D3b[j];

                                        /* Rotate to Leg Base frame       */

ak2[0][0] = -HALF;
ak2[0][1] = -SR3D2;
ak2[0][2] = .0;
ak2[1][0] = SR3D2;
ak2[1][1] = -HALF;
ak2[1][2] = .0;
ak2[2][0] = .0;
ak2[2][1] = .0;
ak2[2][2] = 1.0;

ak3[0][0] = -HALF;
ak3[0][1] = SR3D2;
ak3[0][2] = .0;
ak3[1][0] = -SR3D2;
ak3[1][1] = -HALF;
ak3[1][2] = .0;
ak3[2][0] = .0;
ak3[2][1] = .0;
ak3[2][2] = 1.0;

for(j=0;j<3;j++) _D1[j] = D1b[j];       /* Compute phi & theta  motor angles  */
matmpy(ak2,D2b,_D2);
matmpy(ak3,D3b,_D3);

dlc = sqrt(d1c2);
```

```
d2c = sqrt(d2c2);
d3c = sqrt(d3c2);

phi1c = atan2(_D1[1],d1c);
the1c = asin(-_D1[0]/sqrt(_D1[0]*_D1[0] + _D1[2]*_D1[2]));

phi2c = atan2(_D2[1],d2c);
the2c = asin(-_D2[0]/sqrt(_D2[0]*_D2[0] + _D2[2]*_D2[2]));

phi3c = atan2(_D3[1],d3c);
the3c = asin(-_D3[0]/sqrt(_D3[0]*_D3[0] + _D3[2]*_D3[2]));

/*.....*/
                        /* Set output values   */
sdata->d1     = d1c;
sdata->the1   = the1c;
sdata->phi1   = phi1c;
sdata->d2     = d2c;
sdata->the2   = the2c;
sdata->phi2   = phi2c;
sdata->d3     = d3c;
sdata->the3   = the3c;
sdata->phi3   = phi3c;

return;
}

/*.....End of orient function.....*/

/* ..... Start of Velocity Control Function ..... */

void controller(sdata)

struct sensor *sdata;

{
int j;
float dat1,dat2,dat3;
        d1    = sdata->d1;          /* Transfer input data from global storage */
        the1  = sdata->the1;
        phi1= sdata->phi1;
        d2    = sdata->d2;
        the2= sdata->the2;
```

```
    phi2=  sdata->phi2;
    dphi2= sdata->dphi2;
    tha3 = sdata->tha3;
    phi3 = sdata->phi3;

                                                    /* Get desired linear & angular velocities */
    VEL[0]    = sdata->velx;
    VEL[1]    = sdata->vely;
    VEL[2]    = sdata->velz;
/*---djl---
    ARATE[0] = sdata->wx;
    ARATE[1] = sdata->wy;
    ARATE[2] = sdata->wz;
---djl-----*/
    pval[0]   = sdata->velx;
    pval[1]   = sdata->vely;
    pval[2]   = sdata->velz;
    vrate[0] = sdata->wx;
    vrate[1] = sdata->wy;
    vrate[2] = sdata->wz;
                                                    /* Compute sines & cosines      */
    sthe1 = sin(the1);
    cthe1 = cos(the1);
    sphi1 = sin(phi1);
    cphi1 = cos(phi1);

    sthe2 = sin(the2);
    cthe2 = cos(the2);
    sphi2 = sin(phi2);
    cphi2 = cos(phi2);

    stha3 = sin(tha3);
    ctha3= cos(tha3);
    sphi3 = sin(phi3);
    cphi3 = cos(phi3);

                                                    /* Compute R1,R2,R3,RP vectors */
    R1[0] = -d1*sthe1 + RBASE;
    R1[1] = d1*cthe1*sphi1;
    R1[2] = -d1*cthe1*cphi1;

    R2[0] =   d2*((HALF*sthe2) - (SR3D2*ctha2*sphi2)) - RBD2;
    R2[1] =   d2*(-SR3D2*stha2) - (HALF*cthe2*sphi2)) + SR3D2*RBASE;
    R2[2] =  -d2*cthe2*cphi2;

    R3[0] =   d3*((HALF*stha3) +( SR3D2*ctha3*sphi3)) - RBD2;
    R3[1] =   d3*((SR3D2*stha3) - (HALF*ctha3*sphi3)) - SR3D2*RBASE;
    R3[2] =  -d3*ctha3*cphi3;
```

```
                                                    /* Compute Platform origin position vectors*/
for(j=0; j<3; j++) RP[j] = (1.0/3.0)*(R1[j] + R2[j] + R3[j]);

                                                    /* Compute euler matrix epb[i][j] */
for(j=0;j<3;j++) XP[j] = (R1[j] - RP[j])/RPLAT;
for(j=0;j<3;j++) YP[j] = (R2[j] - R3[j])*(SR3D3/RPLAT);
ZP[0] = (XP[1]*YP[2]) - (XP[2]*YP[1]);
ZP[1] = (XP[2]*YP[0]) - (XP[0]*YP[2]);
ZP[2] = (XP[0]*YP[1]) - (XP[1]*YP[0]);

for(j=0;j<3;j++) epb[0][j] = XP[j];
for(j=0;j<3;j++) epb[1][j] = YP[j];
for(j=0;j<3;j++) epb[2][j] = ZP[j];

                                                    /* Obtain euler matrix ebp[i][j]                    */
transpose(epb,ebp);
/*----dji----*/
/*
matmpy(ebp,pval,VEL);
*/
matmpy(ebp,wrate,ARATE);
/*----dji----*/

                                                    /* Compute Leg postion wrt Sp in Sb                 */
for(j=0;j<3;j++) RP1[j] = R1[j] - RP[j];
for(j=0;j<3;j++) RP2[j] = R2[j] - RP[j];
for(j=0;j<3;j++) RP3[j] = R3[j] - RP[j];

                                                    /* Compute linear velocity of legs                  */
V1[0] = VEL[0] + (ARATE[1]*RP1[2]) - (ARATE[2]*RP1[1]);
V1[1] = VEL[1] + (ARATE[2]*RP1[0]) - (ARATE[0]*RP1[2]);
V1[2] = VEL[2] + (ARATE[0]*RP1[1]) - (ARATE[1]*RP1[0]);

V2[0] = VEL[0] + (ARATE[1]*RP2[2]) - (ARATE[2]*RP2[1]);
V2[1] = VEL[1] + (ARATE[2]*RP2[0]) - (ARATE[0]*RP2[2]);
V2[2] = VEL[2] + (ARATE[0]*RP2[1]) - (ARATE[1]*RP2[0]);

V3[0] = VEL[0] + (ARATE[1]*RP3[2]) - (ARATE[2]*RP3[1]);
V3[1] = VEL[1] + (ARATE[2]*RP3[0]) - (ARATE[0]*RP3[2]);
V3[2] = VEL[2] + (ARATE[0]*RP3[1]) - (ARATE[1]*RP3[0]);

                                                    /* Compute rate transform matrices                  */
e1[0][0] = .0;
e1[1][0] =  d1*sthe1*sphi1;
e1[2][0] =  d1*cthe1*sphi1;
e1[0][1] = -d1*cthe1;
e1[1][1] =  d1*sthe1*cphi1;
```

```
a1[2][1] =  d1*stha1*sphi1;
a1[0][2] =  -sthe1;
a1[1][2] =  -cthe1*sphi1;
a1[2][2] =  -ctha1*sphi1;

a2[0][0] =  d2*(-SR3D2*ctha2*cphi2);
a2[1][0] =  d2*(-HALF*ctha2*cphi2);
a2[2][0] =  d2*(-stha2*sphi2);
a2[0][1] =  d2*((HALF*ctha2) + (SR3D2*stha2*sphi2));
a2[1][1] =  d2*((-SR3D2*ctha2) +(HALF*stha2*sphi2));
a2[2][1] =  d2*stha2*cphi2;
a2[0][2] =  (( HALF*stha3) -  (SR3D2*ctha3*sphi3));
a2[1][2] =  ((-SR3D2*stha3) - (HALF*ctha3*sphi3));
a2[2][2] =  -ctha3*cphi3;

a3[0][0] =  d3*(SR3D2*ctha3*cphi3);
a3[1][0] =  d3*(  -HALF*ctha3*cphi3);
a3[2][0] =  d3*-stha3*sphi3;
a3[0][1] =  d3*((HALF*ctha3) + (SR3D2*stha3*sphi3));
a3[1][1] =  d3*((SR3D2*ctha3) + (HALF*stha3*sphi3));
a3[2][1] =  d3*stha3*cphi3;
a3[0][2] =  (( HALF*ctha3) + (SR3D2*ctha3*sphi3));
a3[1][2] =  ((SR3D2*stha3) -  (HALF*ctha3*sphi3));
a3[2][2] =  -ctha3*cphi3;           /* Form final matrices */

matinv(e1,a1in,&det1);
matinv(e2,a2in,&det2);
matinv(e3,a3in,&det3);

matmpy(e1in,V1,OUT1);              /* Compute motor rate commands */
matmpy(e2in,V2,OUT2);
matmpy(e3in,V3,OUT3);

phid = OUT1[0];
ph2d = OUT2[0];
ph3d = OUT3[0];
d1d =  OUT1[2];
d2d =  OUT2[2];
d3d =  OUT3[2];

                                   /* Compute ONE SET of euler angles (of 12)    */
                                   /* This set is psi,theta,phi (in order) 3b to Sp */

ANGLE[0] = atan2(epb[1][2],epb[2][2]);
ANGLE[1] = asin(-epb[0][2]);
ANGLE[2] = atan2(epb[0][1],epb[0][0]);

/*.....*/
```

```
                                    /* Transfer Output Data */

    sdata->phidot = phid;
    sdata->ph2dot = ph2d;
    sdata->ph3dot = ph3d;

    sdata->didot  =  did;
    sdata->d2dot  =  d2d;
    sdata->d3dot  =  d3d;

    sdata->dxis = RP[0];
    sdata->dyis = RP[1];
    sdata->dzis = RP[2];

    sdata->phi    =  ANGLE[0];
    sdata->theta  =  ANGLE[1];
    sdata->psi    =  ANGLE[2];

    return;
}
/*.....End of Velocity Control Fn.....*/

void quat(q1,q2,q3,q4, trans)

float q1,q2,q3,q4;
float trans[3][3];
{

    trans[0][0] = (q1*q1 + q2*q2 + q3*q3 + q4*q4);          /*Compute new transformation matrix      */
    trans[0][1] =  2.*(q2*q3 + q1*q4);
    trans[0][2] =  2.*(q2*q4 - q1*q3);
    trans[1][0] =  2.*(q2*q3 - q1*q4);
    trans[1][1] = (q1*q1 -q2*q2 + q3*q3 - q4*q4);
    trans[1][2] =  2.*(q3*q4 + q1*q2);
    trans[2][0] =  2.*(q2*q4 + q1*q3);
    trans[2][1] =  2.*(q3*q4 - q1*q2);
    trans[2][2] = (q1*q1 - q2*q2 - q3*q3 + q4*q4);

return;
}

/*.....*/
.....
void euler(phi,the,psi,mat)
```

```
float phi,the,psi;
float mat[3][3];
{
    float sphi,cphi,sthe,cthe,spsi,cpsi;

    /* ..... Euler Matrix Computation ..... */
    /* Compute euler rotation matrix from doc.vars. to Body */

    sthe = sin(the);
    cthe = cos(the);
    spsi = sin(psi);
    cpsi = cos(psi);
    sphi = sin(phi);
    cphi = cos(phi);

    mat[0][0] = cthe*cpsi;
    mat[0][1] = cthe*spsi;
    mat[0][2] = -sthe;
    mat[1][0] = sphi*sthe*cpsi - cphi*spsi;
    mat[1][1] = sphi*sthe*spsi + cphi*cpsi;
    mat[1][2] = sphi*cthe;
    mat[2][0] = cphi*sthe*cpsi + sphi*spsi;
    mat[2][1] = cphi*sthe*spsi - sphi*cpsi;
    mat[2][2] = cphi*cthe;

    return;
}
/* ..... */
void matmpy(a,b,c)                  /* Matrix(3x3) times vector(1x3)*/
                                    /* Calling sequence:           */
                                    /*   float m[3][3] ;           */
                                    /*   float v[3] ;              */
                                    /*   matmpy(m,v,v)             */
    float a[3][3] ;
    float b[3] ;
    float c[3] ;
{
    float t[3] ;

    t[0] = a[0][0]*b[0] + a[0][1]*b[1] + a[0][2]*b[2] ;
    t[1] = a[1][0]*b[0] + a[1][1]*b[1] + a[1][2]*b[2] ;
```

```
        t[2] = a[2][0]*b[0] + a[2][1]*b[1] + a[2][2]*b[2] ;

        c[0] = t[0] ;
        c[1] = t[1] ;
        c[2] = t[2] ;
        }
/*  ..................................... End "matmpy" Code ..................................*/

void matran(a,b,c)
                                /* Matrix transposition multiply*/
                                /* Matrix(3x3) times vector(1x3)*/
                                /* Calling sequence:            */
                                /*   float m[3][3] ;            */
                                /*   float v[3] ;               */
                                /*   matran(m,v,v)              */
        float a[3][3] ;
        float b[3] ;
        float c[3] ;

        {
        float t[3] ;

        t[0] = a[0][0]*b[0] + a[1][0]*b[1] + a[2][0]*b[2] ;
        t[1] = a[0][1]*b[0] + a[1][1]*b[1] + a[2][1]*b[2] ;
        t[2] = a[0][2]*b[0] + a[1][2]*b[1] + a[2][2]*b[2] ;

        c[0] = t[0] ;
        c[1] = t[1] ;
        c[2] = t[2] ;
        }
/*  ..................... End "matran" Code ..................................*/

void matinv(a,b,det)
                                /* Matrix (3x3) Inverse & Determinant)   */

                                /* Calling sequence:            */
                                /*   float m[3][3] ;            */
                                /*   float n[3][3] ;            */
                                /*   float *det                 */
                                /*   matinv(m,n,&det)   */

                                /* Cramer's Rule used to compute inverse.                    */
                                /* Inverse of m to n (with determinant returned always) .    */
                                /* If dat "smaller" than "tiny", inverse not returned   .    */

        float a[3][3] ;
        float b[3][3] ;
```

```
float *det ;

{
*det   =   a[0][0] * (a[1][1]*a[2][2] - a[1][2]*a[2][1])
         - a[1][0] * (a[2][1]*a[0][2] - a[0][1]*a[2][2])
         + a[2][0] * (a[0][1]*a[1][2] - a[1][1]*a[0][2]);

if (fabs(*det)<TINY) return;

temp = 1.0/(*det);

b[0][0] =  temp * (a[1][1]*a[2][2] - a[1][2]*a[2][1]);
b[1][0] = -temp * (a[1][0]*a[2][2] - a[1][2]*a[2][0]);
b[2][0] =  temp * (a[1][0]*a[2][1] - a[1][1]*a[2][0]);

b[0][1] = -temp * (a[0][1]*a[2][2] - a[0][2]*a[2][1]);
b[1][1] =  temp * (a[0][0]*a[2][2] - a[0][2]*a[2][0]);
b[2][1] = -temp * (a[0][0]*a[2][1] - a[0][1]*a[2][0]);

b[0][2] =  temp * (a[0][1]*a[1][2] - a[0][2]*a[1][1]);
b[1][2] = -temp * (a[0][0]*a[1][2] - a[0][2]*a[1][0]);
b[2][2] =  temp * (a[0][0]*a[1][1] - a[0][1]*a[1][0]);
}

/*  ..................... End "native" Code ..................................*/

void smult(a,b,c)

                        /* Matrix(3x3) times matrix(3x3) */
                        /* Calling sequence:             */
                        /*   float a[3][3] ;             */
                        /*   float b[3][3] ;             */
                        /*   float c[3][3] ;             */
                        /*   smult(a,b,c)  ;             */
                        /*     (a)x(b) -> (c)            */

float a[3][3] ;
float b[3][3] ;
float c[3][3] ;
{

c[0][0] = a[0][0]*b[0][0] + a[0][1]*b[1][0] + a[0][2]*b[2][0] ;
c[1][0] = a[1][0]*b[0][0] + a[1][1]*b[1][0] + a[1][2]*b[2][0] ;
c[2][0] = a[2][0]*b[0][0] + a[2][1]*b[1][0] + a[2][2]*b[2][0] ;

c[0][1] = a[0][0]*b[0][1] + a[0][1]*b[1][1] + a[0][2]*b[2][1] ;
c[1][1] = a[1][0]*b[0][1] + a[1][1]*b[1][1] + a[1][2]*b[2][1] ;
c[2][1] = a[2][0]*b[0][1] + a[2][1]*b[1][1] + a[2][2]*b[2][1] ;

c[0][2] = a[0][0]*b[0][2] + a[0][1]*b[1][2] + a[0][2]*b[2][2] ;
```

```
    c[1][2] = a[1][0]*b[0][2] + a[1][1]*b[1][2] + a[1][2]*b[2][2] ;
    c[2][2] = a[2][0]*b[0][2] + a[2][1]*b[1][2] + a[2][2]*b[2][2] ;
    }
/*  ..... End "mmult" Code .....*/

void transpose(a,b)

                /* Matrix(3x3) transpose to matrix(3x3) */
                /* calling example:                     */
                /*   float a[3][3] ;                    */
                /*   float b[3][3] ;                    */
                /*   transpose(a,b) ;                   */
                /*     (a)' -> (b)                      */

    float a[3][3] ;
    float b[3][3] ;
    {
    b[0][0] = a[0][0] ;
    b[1][0] = a[0][1] ;
    b[2][0] = a[0][2] ;
    b[0][1] = a[1][0] ;
    b[1][1] = a[1][1] ;
    b[2][1] = a[1][2] ;
    b[0][2] = a[2][0] ;
    b[1][2] = a[2][1] ;
    b[2][2] = a[2][2] ;
    }
/*  ..... End "mmult" Code .....*/
```

```
#define RPLAT   2.5                 /* Platform radius to leg          */
#define RBASE   3.5                 /* Base radius to leg              */
#define HEIGHT  10.0                /* Nominal height of legs at 90 deg.*/
#define RADDEG  57.29577951         /* Degrees per radian              */
#define DEGRAD  0.01745329          /* Radians per degree              */
#define TINY    1.0e-20             /* A "small" number                */
#define SR3D2   0.866025340         /* sqrt(3)/2                       */
#define SR3D3   0.577350327         /* sqrt(3)/3                       */
#define RPD2    RPLAT*0.5           .
#define RBD2    RBASE*0.5
#define HALF    0.5

/* Interface structure for "HandCntrl" I/O data */

typedef struct sensor
    {
    float d1,the1,phi1;             /* Leg #1 length & two angles (Input)  */
    float d2,the2,phi2;             /* Leg #2 length & two angles (Input)  */
    float d3,the3,phi3;             /* Leg #3 length & two angles (Input)  */
    float dels,dalf,dbet;           /* Platform offset from equilibrium    */
    float phi,theta,psi;            /* Platform roll,pitch,yaw  (radians)  */
    float velx,vely,velz;           /* Desired translational rates         */
    float wx,wy,wz;                 /* Desired angular rates (rad./sec.)   */
    float phidot,thdot;             /* Angle & leg rate commands (Output)  */
    float psidot,d1dot;             /* Angle & leg rate commands (Output)  */
    float d2dot,d3dot;              /* Angle & leg rate commands (Output)  */
    };
```

```
/*--User defines specifying type of input conversion desired.--*/

#define OFFSET_BINARY   0
#define VOLTAGE         1
#define CURRENT         2

#define MAX_CARDS       16


/* Each 605's register block takes up 0x10 bytes.
   The nomenclature is as follows:
   ch1lab - ch8lab : channels 1 through 4 least significant bytes.
   ch1mab - ch8mab : channels 1 through 4 most significant bytes.
*/

struct register_format  {
                        unsigned char unde20;
                        unsigned char ch1lab;
                        unsigned char unde21;
                        unsigned char ch1mab;
                        unsigned char unde22;
                        unsigned char ch2lab;
                        unsigned char unde23;
                        unsigned char ch2mab;
                        unsigned char unde24;
                        unsigned char ch3lab;
                        unsigned char unde25;
                        unsigned char ch3mab;
                        unsigned char unde26;
                        unsigned char unde27;
                        unsigned char ch4lab;
                        unsigned char unde27;
                        unsigned char ch4mab;
                        };


/* Data stored by driver for each card defined. */

struct card_data        {
                        struct register_format *reg_base;
                        double range;
                        };
```

```
/* The DISABLE_LEVEL must be set to a level higher than any interrupt
   that could result in one atod driver call being suspended and another
   executed.  This is necessary so that driver queues don't become corrupted.
*/

#define DISABLE_LEVEL           7

#define IO_CHANNEL_CAPACITY     16


/* QUEUE_LENGTH may be increased if one wishes to queue many measurements
   to one card group.  This could occur if one wanted to measure many channels
   starting after some external trigger.
*/

#define QUEUE_LENGTH            16

#define CONVERSION_COMPLETE     1
#define EMPTY_QUEUE             -1


/* Options defines. */

#define DIFFM                   0x01
#define EXTRIG                  0x02
#define OB_TO_D                 0x04
#define POLL                    0x08


/* The control and data registers for one card group(one 600, five 601's)
   take up 0x10 bytes.  The nomenclature is as follows:
   cntr10 - cntr15 : Each card's control register.
   datamsb : The controlling 600's most significant byte data register.
   datalsb : The controlling 600's least significant byte data register.
*/

struct register_format  {
                        unsigned char undef0;
                        unsigned char cntr10;
                        unsigned char undef1;
                        unsigned char datamsb;
                        unsigned char undef2;
                        unsigned char datalsb;
                        unsigned char undef3;
                        unsigned char cntr11;
                        unsigned char undef4;
                        unsigned char cntr12;
```

```
#include "../include/mymath.h"

#define sign(x)  ((x >= 0) ? 1.1 : -1)
#define PI       3.14159265358979323846

double atan2(y,x)
double y;
double x;
{
if (x > 0)  return(atan(y/x));
if (x < 0)  return(sign(y)*(PI-atan(fabs(y/x))));
if (y != 0) return(sign(y)*PI/2);
return(0);
}

double csign(a,b)
double a,b;
{
double X,Y;
if (b < 0.0)
        x = -1.0;
    else
        x = 1.0;
y = a*x;
return(y);
}

double myfmod(x,y)
double x,y;
{
double z;
z = x/y;
return (double)(z - (double)((int)z)*y);
}
```

```
                                unsigned char undef5;
                                unsigned char cntr13;
                                unsigned char undef6;
                                unsigned char cntr14;
                                unsigned char undef7;
                                unsigned char cntr15;
                                };

/* Data stored for use upon command completion. */

struct parameter_packet {
                        unsigned long channel;
                        unsigned long options;
                        unsigned long *datamb;
                        unsigned long *statmb;
                        };

/* Data defining each card group. */

struct card_data        {
                        struct register_format *reg_base;
                        unsigned long channel_number;
                        double range;
                        };

/* Queue format for each card group. */

struct queue_format     {
                        struct parameter_packet queue[QUEUE_LENGTH];
                        unsigned long queue_head;
                        unsigned long queue_tail;
                        };
```

```
/*    @(#)math.h 1.23 88/03/03 SMI    */

/*
 * Copyright (c) 1988 by Sun Microsystems, Inc.
 */

/*
                #include <math.h>

defines all the public functions implemented in libm.a.

*/

#ifndef M_SQRT1_2
#include <floatingpoint.h>
/* Contains definitions for types and
                                        functions implemented in libc.a.    */

/*      4.3 BSD functions: math.h       4.6     9/11/85 */

extern int      finite();
extern double fabs(), floor(), ceil(), rint();
extern double hypot();
extern double copysign();
extern double sqrt();
extern double scalb(), frexp();
extern double asin(), acos(), atanh();
extern double erf(), erfc();
extern double exp(), expm1(), log(), log10(), log1p(), pow()
extern double lgamma();
extern double j0(), j1(), jn(), y0(), y1(), yn();
extern double sin(), cos(), tan(), asin(), acos(), atan(), atan2();
extern double sinh(), cosh(), tanh();
extern double cbrt();

/*      Sun definitions.        */

enum fp_pi_type {               /* Implemented precisions for trigonometric
                                   argument reduction. */
        fp_pi_infinite  = 0,    /* Infinite-precision approximation to pi. */
        fp_pi_66        = 1,    /* 66-bit approximation to pi. */
        fp_pi_53        = 2     /* 53-bit approximation to pi. */
        } ;

extern enum fp_pi_type fp_pi ;  /* PI precision to use for trigonometric
                                   argument reduction. */
```

```
/*      Functions callable from C, intended to support IEEE arithmetic. */

extern enum fp_class_type fp_class() ;
extern int ilogb(), irint(), signbit() ;
extern int isinf(), isnan(), isnormal(), issubnormal(), iszero() ;
extern double nextafter(), remainder() ;
extern double logb(), significand(), scalb(), scalbn();
extern double min_subnormal(), max_subnormal();
extern double min_normal(), max_normal();
extern double infinity(), quiet_nan(), signaling_nan();

/*      Functions callable from C, intended to support Fortran.         */

extern double log2(), exp10(), exp2(), aint(), anint() ;
extern int nint() ;
extern void   sincos();

/*      Sun FUNCTIONS for C Programmers for IEEE floating point. */

extern int ieee_flags ();
extern int ieee_handler ();

/*      Single-precision functions callable from Fortran, Pascal, Modula-2, etc.,
        take float* arguments instead of double and
        return FLOATFUNCTIONTYPE results instead of double.
        RETURNFLOAT is used to return a float function value without conversion to
        double.
        ASSIGNFLOAT is used to get the float value out of a FLOATFUNCTIONTYPE result.
        We don't want you to have to think about -fsingle2.     *

        Some internal library functions pass float parameters as 32-bit values,
        disguised as FLOATPARAMETER.  FLOATPARAMETERVALUE(x) extracts the
        float value from the FLOATPARAMETER.
*/

/*      mc68000 returns float results in d0, same as int        */

#ifdef mc68000
#define FLOATFUNCTIONTYPE       int
#define RETURNFLOAT(x)          return (*(int *)(&(x)))
#define ASSIGNFLOAT(x,y)        *(int *)(&x) = y
#endif

/*      sparc returns float results in %f0, same as top half of double  */

#ifdef sparc
#define FLOATFUNCTIONTYPE       double
```

```
#define RETURNFLOAT(x)          { union {double _d ; float _f } _kluge ; _kluge._f = (x) ; return _kluge._d ; }
#define ASSIGNFLOAT(x,y)        { union {double _d ; float _f } _kluge ; _kluge._d = (y) ; x = _kluge._f ; }
#endif

/*      i386 returns float results on stack as extended, same as double */

#ifdef i386
#define FLOATFUNCTIONTYPE       float
#define RETURNFLOAT(x)          return (x)
#define ASSIGNFLOAT(x,y)        x = y
#endif

/*      So far everybody passes float parameters as 32 bits on stack, same as int.      */

#define FLOATPARAMETER          int
#define FLOATPARAMETERVALUE(x)  (*(float *)(&(x)))

extern int      ir_finite_();
extern FLOATFUNCTIONTYPE r_fabs_(), r_floor_(), r_ceil_(), r_rint_();
extern FLOATFUNCTIONTYPE r_hypot_();
extern FLOATFUNCTIONTYPE r_copysign_();
extern FLOATFUNCTIONTYPE r_sqrt_();
extern FLOATFUNCTIONTYPE r_asinh_(), r_acosh_(), r_atanh_();
extern FLOATFUNCTIONTYPE r_erf_(), r_erfc_();
extern FLOATFUNCTIONTYPE r_exp_(), r_expm1_(), r_log_(), r_log10_(), r_log1p_();
extern FLOATFUNCTIONTYPE r_pow_();
extern FLOATFUNCTIONTYPE r_lgamma_();
extern FLOATFUNCTIONTYPE r_j0_(), r_j1_(), r_jn_(), r_y0_(), r_y1_(), r_yn_();
extern FLOATFUNCTIONTYPE r_sin_(), r_cos_(), r_tan_(), r_asin_(), r_acos_();
extern FLOATFUNCTIONTYPE r_atan_(), r_atan2_();
extern FLOATFUNCTIONTYPE r_sinh_(), r_cosh_(), r_tanh_();
extern FLOATFUNCTIONTYPE r_cbrt_();
extern int ir_ilogb_(), ir_irint_(), ir_signbit_() ;
extern int ir_isinf_(), ir_isnan_(),
           ir_isubnormal_(), ir_ismormal_(), ir_iszero_() ;
extern enum fp_oless_type ir_fp_oless_();
extern FLOATFUNCTIONTYPE r_nextafter_(), r_remainder_() ;
extern FLOATFUNCTIONTYPE r_log2_(), r_exp10_(), r_exp2_(), r_sint_(), r_snint_() ;
extern int ir_nint_() ;
extern FLOATFUNCTIONTYPE r_fmod_();
extern FLOATFUNCTIONTYPE r_logb_(), r_significand_(), r_scalb_(), r_scalbn_();
extern FLOATFUNCTIONTYPE r_min_subnormal_(), r_max_subnormal_();
extern FLOATFUNCTIONTYPE r_min_normal_(), r_max_normal_();
extern FLOATFUNCTIONTYPE r_infinity_(), r_quiet_nan_(), r_signaling_nan_();
extern void r_sincos_();

/*      Constants, variables, and functions from System V */
```

```
#define _ABS(x) ((x) < 0 ? -(x) : (x))

#define HUGE_VAL        (infinity())    /* Produces IEEE infinity. */
#define HUGE            (infinity())    /* For historical compatibility. */

#define DOMAIN          1
#define SING            2
#define OVERFLOW        3
#define UNDERFLOW       4
#define TLOSS           5
#define PLOSS           6

struct exception {
        int type;
        char *name;
        double arg1;
        double arg2;
        double retval;
};

extern int signgam;

extern double fmod();
extern int matherr();

/* First three have to be defined exactly as in values.h including spacing! */

#define M_LN2   0.69314718055994530942
#define M_PI    3.14159265358979323846
#define M_SQRT2 1.41421356237309504880

#define M_E             2.71828182845904523354
#define M_LOG2E         1.44269504088896340074
#define M_LOG10E        0.43429448190325182765
#define M_LN10          2.30258509299404568402
#define M_PI_2          1.57079632679489661923
#define M_PI_4          0.78539816339744830962
#define M_1_PI          0.31830988618379067154
#define M_2_PI          0.63661977236758134308
#define M_2_SQRTPI      1.12837916709551257390
#define M_SQRT_2        0.70710678118654752440
#define _POLY1(x, c)    ((c)[0] * (x) + (c)[1])
#define _POLY2(x, c)    (_POLY1((x), (c)) * (x) + (c)[2])
#define _POLY3(x, c)    (_POLY2((x), (c)) * (x) + (c)[3])
#define _POLY4(x, c)    (_POLY3((x), (c)) * (x) + (c)[4])
#define _POLY5(x, c)    (_POLY4((x), (c)) * (x) + (c)[5])
```

```
#define _POLY5(x, c)    _POLY5((x), (c)) * (x) + (c)[6])
#define _POLY6(x, c)    _POLY6((x), (c)) * (x) + (c)[7])
#define _POLY7(x, c)    _POLY7((x), (c)) * (x) + (c)[8])
#define _POLY8(x, c)    _POLY8((x), (c)) * (x) + (c)[9])

/*
        Deprecated functions for compatibility with past.
        Changes planned for future.
*/

extern double cabs();       /* Use double hypot(x,y)
                               Traditional cabs usage is confused -
                               is its argument two doubles or one struct?  */
extern double drem();       /* Use double remainder(x,y)
                               drem will disappear in a future release.    */
extern double gamma();      /* Use double lgamma(x)
                               to compute log of gamma function.
                               Name gamma is reserved for true gamma function
                               to appear in a future release.              */
extern double idexp();      /* Use double scalbn(x,n)
                               idexp may disappear in a future release     */

#endif
```

```
#include "../include/mymath.h"

/*.....BOWL DEMO DECLARATIONS.....*/
static double RADIUS = 6.0;          /* Radius of bowl shape centered above origin      */
static double ALP = .3;
static double PID2 = 1.57079633;     /* = (1/2)*PI radians or 90 deg.                   */
/*.....*/
.....*/

void bowl(PX,PY,xbowl,ybowl,zbowl,phibo,thebo,psibo)

double PX,PY;
double *xbowl,*ybowl,*zbowl;    /* Bowl parameters                    -1.<PI<1.    */
double *phibo,*thebo,*psibo     /* Bowl rel.coord. wrt platform coord. origin      */
                                /* Bowl surface attitudes                          */
{
double phi,the;

phi = ALP*PX;
the = ALP*PY;
*xbowl = -RADIUS*sin(the)*cos(phi);
*ybowl = RADIUS*sin(phi);
*zbowl = RADIUS*cos(the)*cos(phi) - RADIUS;
*phibo = -phi;
*thebo = -the;
*psibo = 0.0;
/*---
*xbowl = -RADIUS*sin(the);
*ybowl = RADIUS*cos(the)*sin(phi);
*zbowl = RADIUS*cos(the)*cos(phi) - RADIUS;
*phibo = -phi;
*thebo = -the;
*psibo = 0.0;
---*/
}
```

```
typedef struct {
        char    *cmd;
        int     size;
        int     (*procedure);
        ARG     *argtab;
} CMD_STRUCT;

/* system routines */

extern  help();
extern  usage();

/* vp routines */

extern vp_bol();
extern vp_ana();
extern vp_dof();
extern vp_lin();
extern vp_mod();
extern vp_roc();
extern vp_sys();
extern vp_xxx();

static ARG vptab[]={
        {'b',PROC,(int *)vp_bol,        "change BREAKOUT characteristics"},
        {'d',PROC,(int *)vp_dof,        "toggle 3/6 DEGREES-OF-freedom"},
        {'e',PROC,(int *)vp_ena,        "ENABLE integrators"},
        {'g',PROC,(int *)vp_xxx,        "change GAINS"},
        {'l',PROC,(int *)vp_lin,        "change LINEAR spring rate"},
        {'m',PROC,(int *)vp_mod,        "toggle model (on/off)"},
        {'r',PROC,(int *)vp_roc,        "change ROTATIONAL spring rate"},
        {'s',PROC,(int *)vp_sys,        "display system STATUS"},
};

#define VP_TAB_SIZE             (sizeof(vptab)      / sizeof(ARG))

CMD_STRUCT cmdtab[] =
{
        "vp",           VP_TAB_SIZE,            (int *)usage,   vptab,
        "help",         0,                      (int *)help,    0,
        "",             0,                      0,              0
};
```

```
ASM     = a20
CC      = ccom -I/n/orion/ant0/packages/qhs/include -X20 -X22 -X29 -X35 -X98 -X99 -X122 -X123 -X140

OFILES  = int_lsr.obj myfunc50hz.obj hs4.obj cmath.obj bow1.obj hyst.obj
IFILES  = int_lsr,myfunc50hz,hs4,cmath,bow1,hyst

lib: lsrlib.olb
lsrlib.olb: $(OFILES)
        lib68 lsrlib=$(LFILES)

.c.obj:
        $(CC) $*.c
        $(ASM) $*,$*=$*
        rm $*.asm $*.lst

.asm.obj:
        $(ASM) $*,$*=$*

.SUFFIXES: .obj .asm .x .c
```

```
/*
 */      Getargs.h       Typedefs and defines needed for getargs

#define INTEGER     0
#define BOOLEAN     1
#define CHARACTER   2
#define STRING      3
#define PROC        4

typedef struct
{
        unsigned    arg  : 7  ;   /* Command line switch      */
        unsigned    type : 4  ;   /* variable type            */
        int         *variable ;   /* pointer to variable      */
        char        *errmsg   ;   /* pointer to error message */
}
ARG;

extern int getargs();
```

```
/* this file does a complete context save of the 68881
   and saves all the 68020 registers.

        int_exit.h must be included at subroutine exit time
        if this file is used.
        */
    asm("   MOVEM.L D0-D7/A0-A5,-(SP)");
    asm("   FMOVE.L FPCR/FPSR/FPIAR,-(SP)");
    asm("   TST.B   (SP)+");
    asm("   DC.L    $6710000C");                    /* beq to null save */
    asm("   FMOVEM  FP0-FP7,-(SP)");
    asm("   FMOVEM  FPCR/FPSR/FPIAR,-(SP)");
    asm("   BRA     -(SP)");                        /* null save */
    asm("   NOP");
```

```
/* this include file restores the 68881 after a context switch
   It also restores all 68020 registers and does an RTE on exit.

      It must be used if int_enter.h was included on entry to
      the subroutine */

asm("   TST.B   (SP)+");
asm("   BEQ.L   &$70000C");                    /* beq to null restore */
asm("   ADDQ.L  #2,SP");
asm("   FMOVEM  (SP)+,FPCR/FPSR/FPIAR");
asm("   FMOVEM  (SP)+,FP0-FP7");
asm("   FRESTORE (SP)+");                      /* null restore */
asm("   MOVEM.L (SP)+,D0-D7/A0-A5");
asm("   RTE");
```

```
#define mfp_base        0xfff80000

#define mfp_gpip        (mfp_base + 0x01)
#define mfp_aer         (mfp_base + 0x03)
#define mfp_ddr         (mfp_base + 0x05)
#define mfp_iera        (mfp_base + 0x07)
#define mfp_ierb        (mfp_base + 0x09)
#define mfp_ipra        (mfp_base + 0x0B)
#define mfp_iprb        (mfp_base + 0x0D)
#define mfp_isra        (mfp_base + 0x0F)
#define mfp_isrb        (mfp_base + 0x11)
#define mfp_imra        (mfp_base + 0x13)
#define mfp_imrb        (mfp_base + 0x15)
#define mfp_vr          (mfp_base + 0x17)
#define mfp_tacr        (mfp_base + 0x19)
#define mfp_tbcr        (mfp_base + 0x1B)
#define mfp_tcddr       (mfp_base + 0x1D)
#define mfp_tadr        (mfp_base + 0x1F)
#define mfp_tbdr        (mfp_base + 0x21)
#define mfp_tcdr        (mfp_base + 0x23)
#define mfp_tddr        (mfp_base + 0x25)
#define mfp_scr         (mfp_base + 0x27)
#define mfp_ucr         (mfp_base + 0x29)
#define mfp_rsr         (mfp_base + 0x2B)
#define mfp_tsr         (mfp_base + 0x2D)
#define mfp_udr         (mfp_base + 0x2F)


/* Vmebus system memory map. */

/* MVME316, MVME600, MVME693 VIO, ADC and DAC definitions. */

#define VIO_VME_START   0xFFFE0000

#define ADC_IO_START    0x0400
#define DAC1_IO_START   0x0000
#define DAC2_IO_START   0x0200

#define ADC_VME_START   (VIO_VME_START + ADC_IO_START)
#define DAC1_VME_START  (VIO_VME_START + DAC1_IO_START)
#define DAC2_VME_START  (VIO_VME_START + DAC2_IO_START)

/* MVME133 executive cpu definitions. */

#define EXEC_CPU_DPRAM_START    0x200000
#define EXEC_CPU_DPRAM_END      0x2FFFFF
```

```
asm("   FSAVE   -(SP)");
asm("   TST.B   (SP)");
asm("   DC.L    $6700000C");
asm("   FMOVEM  FP0-FP7,-(SP)");
asm("   FMOVEM  FPCR/FPSR/FPIAR,-(SP)");
asm("   ST      -(SP)");

asm("   TST.B   (SP)+");
asm("   DC.L    $6700000C");
asm("   ADD.L   #2,SP");
asm("   FMOVEM  (SP)+,FPCR/FPSR/FPIAR");
asm("   FMOVEM  (SP)+,FP0-FP7");
asm("   FRESTORE    (SP)+");
```

```
/* scc8530.h - header file for scc chip */

/*
modification history
--------------------
01b,08nov87,dnw  fixed definition of SCC_WR4_SDLC (was 0x10, should be 0x20).
01a,06jul,llk+jlf   written
*/

#ifndef INCscc8530h
#define INCscc8530h     1

/* bit values for write register 0 */
/* command register */

#define SCC_WR0_SEL_WR0         0x00
#define SCC_WR0_SEL_WR1         0x01
#define SCC_WR0_SEL_WR2         0x02
#define SCC_WR0_SEL_WR3         0x03
#define SCC_WR0_SEL_WR4         0x04
#define SCC_WR0_SEL_WR5         0x05
#define SCC_WR0_SEL_WR6         0x06
#define SCC_WR0_SEL_WR7         0x07
#define SCC_WR0_SEL_WR8         0x08
#define SCC_WR0_SEL_WR9         0x09
#define SCC_WR0_SEL_WR10        0x0a
#define SCC_WR0_SEL_WR11        0x0b
#define SCC_WR0_SEL_WR12        0x0c
#define SCC_WR0_SEL_WR13        0x0d
#define SCC_WR0_SEL_WR14        0x0e
#define SCC_WR0_SEL_WR15        0x0f
#define SCC_WR0_NULL_CODE       0x00
#define SCC_WR0_RST_INT         0x10
#define SCC_WR0_SEND_ABORT      0x18
#define SCC_WR0_EN_INT_RX       0x20
#define SCC_WR0_RST_TX_INT      0x28
#define SCC_WR0_ERR_RST         0x30
#define SCC_WR0_RST_HI_IUS      0x38
#define SCC_WR0_RST_RX_CRC      0x40
#define SCC_WR0_RST_TX_CRC      0x80
#define SCC_WR0_RST_TX_UND      0xc0

/* write register 2 */
/* interrupt vector */

/* bit values for write register 1 */
/* tx/rx interrupt and data transfer mode definition */

#define SCC_WR1_EXT_INT_EN      0x01
#define SCC_WR1_TX_INT_EN       0x02
#define SCC_WR1_PARITY          0x40
#define SCC_WR1_RX_INT_DIS      0x00
#define SCC_WR1_RX_INT_FIR      0x08
#define SCC_WR1_INT_ALL_RX      0x10
#define SCC_WR1_RX_INT_SPE      0x18
#define SCC_WR1_RDMA_RECTR      0x20
#define SCC_WR1_RDMA_FUNC       0x40
#define SCC_WR1_RDMA_EN         0x80

/* bit values for write register 3 */
/* receive parameters and control */

#define SCC_WR3_RX_EN           0x01
#define SCC_WR3_SYNC_CHAR       0x02
#define SCC_WR3_ADR_SEARCH      0x04
#define SCC_WR3_RX_CRC_EN       0x08
#define SCC_WR3_ENTER_HUNT      0x10
#define SCC_WR3_AUTO_EN         0x20
#define SCC_WR3_RX_5_BITS       0x00
#define SCC_WR3_RX_7_BITS       0x40
#define SCC_WR3_RX_6_BITS       0x80
#define SCC_WR3_RX_8_BITS       0xc0

/* bit values for write register 4 */
/* tx/rx misc parameters and modes */

#define SCC_WR4_PAR_EN          0x01
#define SCC_WR4_PAR_EVEN        0x02
#define SCC_WR4_SYNC_EN         0x00
#define SCC_WR4_1_STOP          0x04
#define SCC_WR4_2_STOP          0x0c
#define SCC_WR4_8_SYNC          0x00
#define SCC_WR4_16_SYNC         0x10
#define SCC_WR4_SDLC            0x20
#define SCC_WR4_EXT_SYNC        0x30
#define SCC_WR4_1_CLOCK         0x00
#define SCC_WR4_16_CLOCK        0x40
#define SCC_WR4_32_CLOCK        0x80
#define SCC_WR4_64_CLOCK        0xc0

/* bit values for write register 5 */
/* transmit parameter and controls */

#define SCC_WR5_TX_CRC_EN       0x01
```

```
/* bit values for write register 11 */
/* clock mode control */

#define SCC_WR11_OUT_XTAL          0x00
#define SCC_WR11_OUT_TX_CLK        0x01
#define SCC_WR11_OUT_BR_GEN        0x02
#define SCC_WR11_OUT_DPLL          0x03
#define SCC_WR11_TRXC_OI           0x04
#define SCC_WR11_TX_TRXC           0x08
#define SCC_WR11_RX_TRXC           0x10
#define SCC_WR11_TX_BR_GEN         0x10
#define SCC_WR11_TX_DPLL           0x18
#define SCC_WR11_RX_RTXC           0x00
#define SCC_WR11_RX_TRXC           0x20
#define SCC_WR11_TX_BR_GEN         0x40
#define SCC_WR11_TX_DPLL           0x60
#define SCC_WR11_RTXC_XTAL         0x80

/* write register 12 */
/* lower byte of baud rate generator time constant */

/* write register 13 */
/* upper byte of baud rate generator time constant */

/* bit values for write register 14 */
/* misc control bits */

#define SCC_WR14_BR_EN             0x01
#define SCC_WR14_BR_SRC            0x02
#define SCC_WR14_DTR_FUNC          0x04
#define SCC_WR14_AUTO_ECHO         0x08
#define SCC_WR14_LCL_LOOP          0x10
#define SCC_WR14_AUTO_RQST         0x20
#define SCC_WR14_START_CLK         0x40
#define SCC_WR14_DIS_DPLL          0x60
#define SCC_WR14_SRC_BR            0x80
#define SCC_WR14_SRC_RTXC          0xa0
#define SCC_WR14_BR_PCLK           0xc0
#define SCC_WR14_NRZI              0xe0

/* bit values for write register 15 */
/* external/status interrupt control */

#define SCC_WR15_ZERO_CNT          0x02
#define SCC_WR15_CD_IE             0x08
#define SCC_WR15_SYNC_IE           0x10

#define SCC_WR5_RTS                0x02
#define SCC_WR5_SDLC               0x04
#define SCC_WR5_TX_EN              0x08
#define SCC_WR5_SEND_BRK           0x10

#define SCC_WR5_TX_5_BITS          0x00
#define SCC_WR5_TX_7_BITS          0x20
#define SCC_WR5_TX_6_BITS          0x40
#define SCC_WR5_TX_8_BITS          0x60
#define SCC_WR5_DTR                0x80

/* write register 6 */
/* sync chars or sdlc address field */

/* write register 7 */
/* sync char or sdlc flag */

/* write register 8 */
/* transmit buffer */

/* bit values for write register 9 */
/* master interrupt control */

#define SCC_WR9_VIS                0x01
#define SCC_WR9_NV                 0x02
#define SCC_WR9_DLC                0x04
#define SCC_WR9_MIE                0x08
#define SCC_WR9_STATUS_HI          0x10
#define SCC_WR9_SO_HDR_RST         0x40
#define SCC_WR9_CH_A_RST           0x80
#define SCC_WR9_CH_B_RST           0xc0
#define SCC_WR9_HDWR_RST           0xc0

/* bit values for write register 10 */
/* misc tx/rx control bits */

#define SCC_WR10_6_BIT_SYNC        0x01
#define SCC_WR10_LOOP_MODE         0x02
#define SCC_WR10_ABORT_UNDR        0x04
#define SCC_WR10_MARK_IDLE         0x08
#define SCC_WR10_ACT_POLL          0x10

#define SCC_WR10_NR2               0x00
#define SCC_WR10_NRZI              0x20
#define SCC_WR10_FM1               0x40
#define SCC_WR10_FM0               0x60
#define SCC_WR10_CRC_PRESET        0x80
```

```
#define SCC_WR15_CTS_IE                 0x20
#define SCC_WR15_TX_UND_IE              0x40
#define SCC_WR15_BREAK_IE               0x80

/* bit values for read register 0 */
/* tx/rx buffer status and external status */

#define SCC_RR0_RX_AVAIL                0x01
#define SCC_RR0_ZERO_CNT                0x02
#define SCC_RR0_TX_EMPTY                0x04
#define SCC_RR0_CD                      0x08
#define SCC_RR0_SYNC                    0x10
#define SCC_RR0_CTS                     0x20
#define SCC_RR0_TX_UND                  0x40
#define SCC_RR0_BREAK                   0x80

/* bit values for read register 1 */

#define SCC_RR1_ALL_SENT                0x01
#define SCC_RR1_RES_CD_2                0x02
#define SCC_RR1_RES_CD_1                0x04
#define SCC_RR1_RES_CD_0                0x08
#define SCC_RR1_PAR_ERR                 0x10
#define SCC_RR1_RX_OV_ERR               0x20
#define SCC_RR1_CRC_ERR                 0x40
#define SCC_RR1_END_FRAME               0x80

/* read register 2 */
/* interrupt vector */

/* bit values for read register 3 */
/* interrupt pending register */

#define SCC_RR3_B_EXT_IP                0x01
#define SCC_RR3_B_TX_IP                 0x02
#define SCC_RR3_B_RX_IP                 0x04
#define SCC_RR3_A_EXT_IP                0x08
#define SCC_RR3_A_TX_IP                 0x10
#define SCC_RR3_A_RX_IP                 0x20

/* read register 8 */
/* receive data register */

/* bit values for read register 10 */
/* misc status bits */

#define SCC_RR10_ON_LOOP                0x02

#define SCC_RR10_LOOP_SEND              0x10
#define SCC_RR10_2_CLK_MIS              0x40
#define SCC_RR10_1_CLK_MIS              0x80

/* read register 12 */
/* lower byte of time constant */

/* read register 13 */
/* upper byte of time constant */

char    prompt[11];
char    disp_str[4];
char    scc_none[6];

/* bit values for read register 15 */
/* external/status ie bits */

#define SCC_RR15_ZERO_CNT               0x02
#define SCC_RR15_CD_IE                  0x08
#define SCC_RR15_SYNC_IE                0x10
#define SCC_RR15_CTS_IE                 0x20
#define SCC_RR15_TX_UND_IE              0x40
#define SCC_RR15_BREAK_IE               0x80

#endif
```

```
/* 0x20 bytes are decoded for the bus interrupter module's registers.
   The nomenclature for the register is as follows:
      cr0 - cr3 : control registers 0 through 3.
      vr0 - vr3 : vector registers 0 through 3.
      err : software reset register.
*/
struct bim_register_format      {
                                unsigned char undef0;
                                unsigned char cr0;
                                unsigned char undef1;
                                unsigned char cr1;
                                unsigned char undef2;
                                unsigned char cr2;
                                unsigned char undef3;
                                unsigned char cr3;
                                unsigned char undef4;
                                unsigned char vr0;
                                unsigned char undef5;
                                unsigned char vr1;
                                unsigned char undef6;
                                unsigned char vr2;
                                unsigned char undef7;
                                unsigned char vr3;
                                unsigned char undef8;
                                unsigned char err;
                                unsigned char undef[0x05];
                                };

                                /* Exception vector locations used. */

                                #define TRAP14          0x0B8           /* vec 0x41: ico          */
                                #define USER01          0x1b4           /* vec 0x42: iprocc       */
                                #define USER02          0x108           /* vec 0x42: iprocc       */
                                #define USER03          0x10c           /* vec 0x43: button 1 */
                                #define USER04          0x110           /* vec 0x44: button 2 */
                                #define USER05          0x114           /* vec 0x45: button 3 */
                                #define USER06          0x118           /* vec 0x46: button 4 */
                                #define TIMERA          0x1b4           /* vec 0x6d: timer a  */
                                #define VMEIRQ3         0x3fc           /* vec 0xff: vme irq3 */

                                #define IPROTO_XFER     0x42
                                #define ICC_SP_RETURN   0x41
```

```
#define A_BASE_ADDR 0xffffe200
#define A_RANGE      10.0
#define B_BASE_ADDR 0xffffe400
#define B_RANGE      10.0
#define C_BASE_ADDR 0xffffe000
#define C_RANGE      10.0
#define C_CHANNELS   16

#define IO_LEVEL     1
#define VME_LEVEL    6
#define VECTOR       219
#define SIM_ADDR     0xffffb200

#define THREE_DOF    0
#define SIX_DOF      1
#define POS_MODE     0
#define RATE_MODE    1
#define INT_OFF      0
#define INT_ON       1
#define ROML_OFF     0
#define ROML_ON      1

#define DEAF                 0.02
#define RATELIM              10.0
#define RPD                  0.0175
#define TAN_POS_SF           2.35*RPD
#define RAD_POS_SF           2.35*RPD
#define LIN_POS_SF           0.167
#define LIN_POS_OFF          10.0
#define MAX_TRANS            1.5
#define MAX_ANGLE            0.25
#define FORCE_UNARMED        5.0
#define FORCE_ARMED          30.0
#define V_PER_IPS            7.162
#define V_PER_TPS            (7.500/4.0)
#define INT_LIM              10.0
#define VOLT_LIM             10.0

extern double MAX_FORCE,MAX_MOMENT;
extern double glob[500][8];

extern struct vpdat
    {
    short fx,fy,fz;
    short mx,my,mz;
    int igo,mod,def,bol;
    double kp,kr;
```

```
    double a,w;
    int stuns;
    int run,ptr;
    double xc,yc,zc;
    double bo,hh;
    double kth;
    }
    vp;
extern struct
    {
    struct
        {
        struct
            {
            int chn;
            int card;
            double val;
            double cmd;
            double err;
            double ler;
            }
            rat,pos,mot;
        }
        lin,rad,tan;
    }
    legl.leg2.leg3;
```

```
asm("    MOVEM.L D0-D2/A0-A1,-(SP)");
```

```
asm(" MOVEM.L (SP)+,D0-D2/A0-A1");
asm(" RTE");
```

Claims

1. A six degree-of-freedom virtual pivot controller (10) comprising:
grip means (28) for receiving externally applied force and torque;
force and torque sensing means (34), connected to said grip means, for sensing the force and torque, from up to six degrees-of-freedom, applied to said grip means;
first support means (30), connected to said sensing means, for supporting said sensing means;
second support means (48) for supporting said hand controller;
at least one variable-length member means (62) having a first flexible connector (32) attached to said first support means (30) and a second flexible connector (60), attached to said second support means (48), for variable supporting said first support means,
wherein said at least one variable-length member means comprises:
translation actuating means (36, 40) connected to said member means (62), for varying the length of said member means;
translational sensing means (38), connected to said member means, for sensing a length of said member means;
angular actuating means (46, 50, 52), connected to said member means, for angularly moving said member means relative to said second support means; and
angular sensing means (44), connected to said member means, for sensing an angular position of said member means relative to said second support means.

2. Controller according to claim 1 further **characterized by** comprising processing and control means (12), connected to said force and torque sensing means (34), to said translational sensing means, to said angular sensing means (38), to said translational actuating means (36, 40) and to said angular actuating means (46, 50, 52), for receiving signals from said force and torque sensing means, said translational sensing means and said angular sensing means, and for sending signals to said translational actuating means and to said angular actuating means.

3. Controller according to claim 2, **characterized in that** said processing and control means (12) sends signals to an external device (18) to be controlled by said hand controller (10), and receives signals for the external device.

4. Controller according to claim 3, **characterized in that** any externally applied force and torque to said grip means (28) is sensed by said force and torque sensing means (34) which in turn sends signals indicating force and torque to said processing and control means (12) which in turn sends signals

indicating certain kinds of control to the external device (18) being controlled which in turn sends signals of action and reflective force of the external device to said processing and control means which in turn sends signals of reflective force and movement to said translational actuating means and to said angular actuating means which in turn provide reflective force, torque and movement in response to the any externally applied force and torque to said grip means.

5. Controller according to claim 4, **characterized in that** said grip means (28) reflects a virtual pivot point of said grip means having to the spring-like reflective force and torque, and movement to the any externally applied force and torque.

6. Controller according to claim 4, **characterized in that** a location of the virtual pivot point and magnitudes of the spring-like reflective force and torque and of movement may be varied via input information to said processing and control means (12).

7. Controller according to claim 1, **characterized in that** said first flexible connector is a ball joint (32);
said second flexible connector is a universal joint (60);
said translation actuating means comprises a first motor (40),
connected to said interface and control means (12), for drawing said actuating means which changes length of said variable length member (62);
said translational sensing means comprises:
a first tachometer (42) connected to the first motor and to said interface and control means; and
a linear potentiometer (38) connected to said linear actuator and to said interface and control means;
said angular actuating means further comprises a second motor (52), connected to said interface and control means, for driving said angular actuating means; and
said angular sensing means comprises:
a first angular potentiometer (44) connected to said universal joint and to said interface and control means; a second angular potentiometer (44) connected to said universal joint and to said interface and control means; and
a second tachometer (54) connected to the second motor (52) and to said interface and control means.

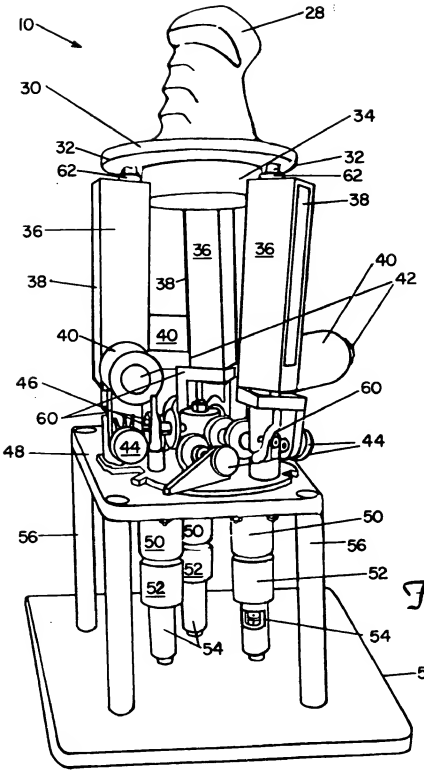
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Fig. 1

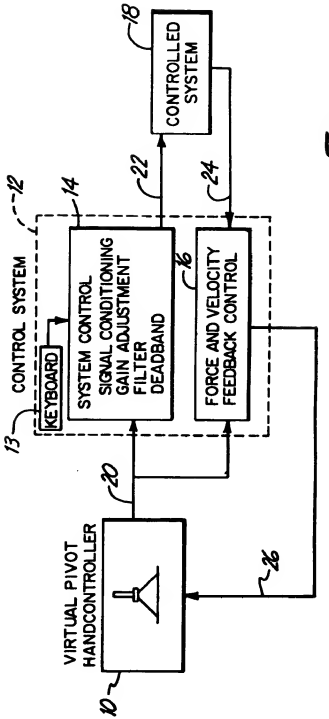

VIRTUAL PIVOT HANDCONTROLLER
10
20
CONTROL SYSTEM
12
13
KEYBOARD
14
SYSTEM CONTROL
SIGNAL CONDITIONING
GAIN ADJUSTMENT
FILTER
DEADBAND
16
FORCE AND VELOCITY FEEDBACK CONTROL
22
24
26
18
CONTROLLED SYSTEM

Fig. 2

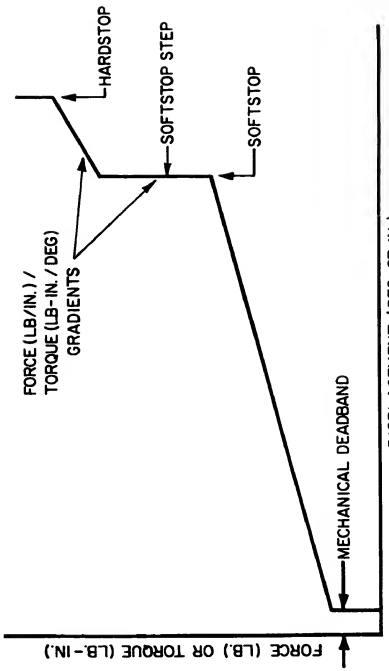

FORCE (LB.) OR TORQUE (LB.-IN.)
DISPLACEMENT (DEG. OR IN.)
MECHANICAL DEADBAND
FORCE (LB/IN.) / TORQUE (LB-IN./DEG) GRADIENTS
SOFTSTOP
SOFTSTOP STEP
HARDSTOP

Fig. 3

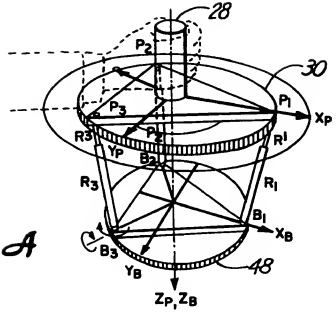


Fig. 4A

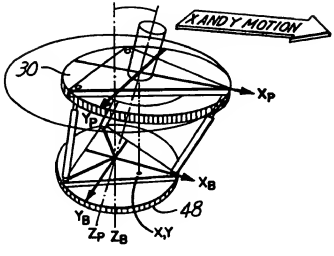


Fig. 4B

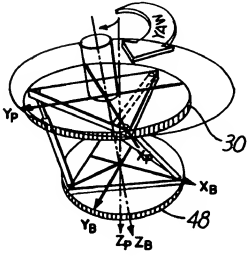


Fig. 4C

34
FORCE/TORQUE SENSOR
CONTROL SYSTEM
66
RS-232 TERMINAL INTERFACE FOR OPERATOR CONTROL OF SENSOR AND ELECTRONICS
13
GAIN
LIMIT
(1/MAX F)
±MAX_TRANS
±MAX_MOMENT
KP
VX
VY
VZ
ωXC
ωYC
ωZC
XP
YP
ZP
ΦP
θP
ΨP
OUTPUT TO EXTERNAL CONTROLLED OBJECT AND INPUT CHANNEL FOR REFLECTED FORCE OR TORQUE "FEEL DYNAMICS" OR ALARMS
18
88

Fig 5A

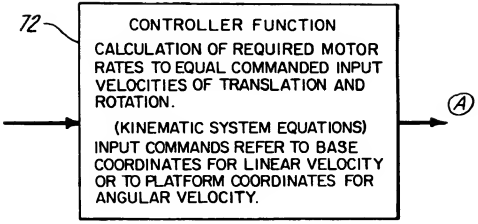
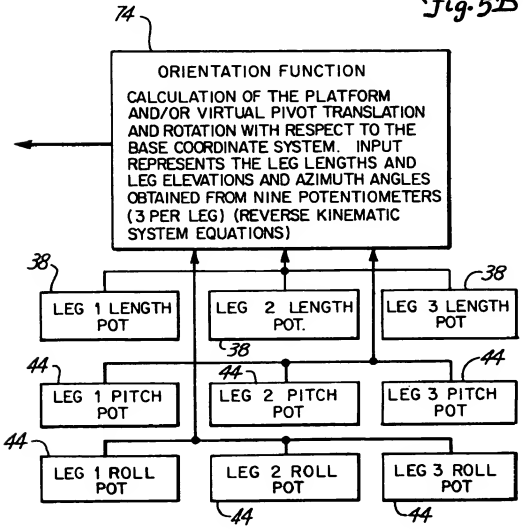
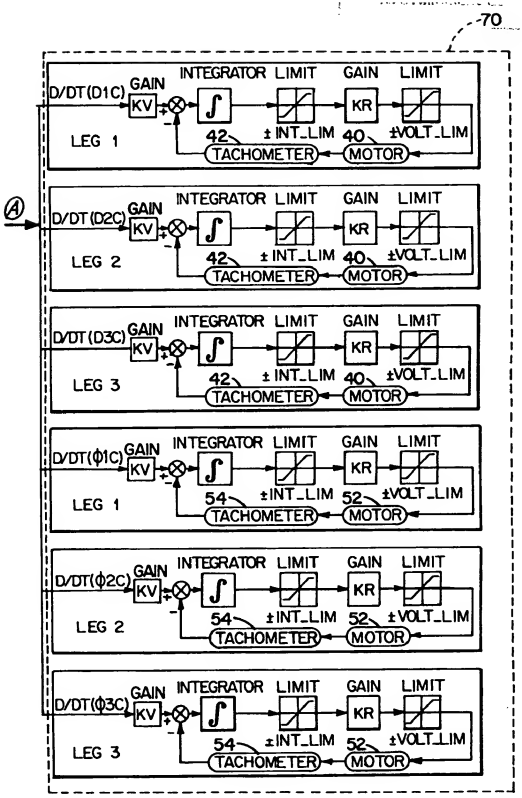

72
CONTROLLER FUNCTION
CALCULATION OF REQUIRED MOTOR RATES TO EQUAL COMMANDED INPUT VELOCITIES OF TRANSLATION AND ROTATION.
(KINEMATIC SYSTEM EQUATIONS) INPUT COMMANDS REFER TO BASE COORDINATES FOR LINEAR VELOCITY OR TO PLATFORM COORDINATES FOR ANGULAR VELOCITY.
A

Fig. 5B


74
ORIENTATION FUNCTION
CALCULATION OF THE PLATFORM AND/OR VIRTUAL PIVOT TRANSLATION AND ROTATION WITH RESPECT TO THE BASE COORDINATE SYSTEM. INPUT REPRESENTS THE LEG LENGTHS AND LEG ELEVATIONS AND AZIMUTH ANGLES OBTAINED FROM NINE POTENTIOMETERS (3 PER LEG) (REVERSE KINEMATIC SYSTEM EQUATIONS)
38
LEG 1 LENGTH POT
LEG 2 LENGTH POT.
LEG 3 LENGTH POT
38
38
44
LEG 1 PITCH POT
LEG 2 PITCH POT
LEG 3 PITCH POT
44
44
44
LEG 1 ROLL POT
LEG 2 ROLL POT
LEG 3 ROLL POT
44
44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A
D/DT(D1C)
D/DT(D2C)
D/DT(D3C)
D/DT(Φ1C)
D/DT(Φ2C)
D/DT(Φ3C)
GAIN
KV
INTEGRATOR LIMIT
GAIN
LIMIT
KR
LEG 1
LEG 2
LEG 3
42
± INT_LIM
40
±VOLT_LIM
TACHOMETER
MOTOR
54
52

Fig. 5C

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 12 2237

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-4 660 828 (WEISS) * the whole document *	1-6	G05G9/04 G05G5/03 G06K11/18
A,D	EP-A-0 363 739 (HONEYWELL) * the whole document *	1-7	G06F3/033 B25J13/02

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G01G
G05G
G06K
G06F
H01H
B64C
B25J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	31 MARCH 1992	DESENA Y HERNANDOREN

CATEGORY OF CITED DOCUMENTS

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